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DESIGN CONCEPTS FOR HELICOPTER PALLETS AND GONDOLAS

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Parsons of California

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of the design concepts investigation and preliminary design of externally suspended cargo pallets and/or gondolas to be utilized with the CH-47, CH-54, and HLH helicopters. Results of the investigation demonstrated that gondolas of two sizes could be coupled to develop full payload capacity of any of the three helicopters. The basic gondola was right rectangular to accommodate vehicles and equipment or break-bulk cargo if required. The investigation and supporting analyses eliminated pallets with lifting points at the base which make it both unstable and structurally

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) inefficient. Therefore, pallets were not considered as a viable design concept. The gondola provides compatibility with ANSI/ISO geometry and can be transported with slings or other load acquisition equipment. The gondola may be introduced at any segment of the through-put supply system to transport vehicles and equipment or break-bulk cargo as required.

EUSTIS DIRECTORATE POSITION STATEMENT

This project generated conceptual designs and preliminary design drawings of a gonodla system selected as the most responsive to support the mission of Army cargo helicopters. The contractor relied on reference material pertaining to logistics, field operational requirements, interviews with prime manufacturers of aircraft, and commercial terminal and helicopter operators. In-depth analyses were conducted to determine aerodynamic, material, structural, performance, and logistic factors and intermode compatibility. Preliminary design drawings generated under this program represent a new approach to a flexible, effective gondola system.

This directorate does not concur with the downward design load factor of 3.0 used in developing structural criteria. A factor of 2.8 is considered to be more realistic in view of guidelines determined by recently completed tests.

Results of this contract are being used to establish programs that will include fabrication of experimental gondola assemblies designed to revised load factors for static/ground testing and flight evaluation.

Mr. S. G. Riggs, Jr., of the Military Operations Technology Division served as Project Engineer for this effort.

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INTRODUCTION

A parametric investigation of the performance requirements for externally suspended helicopter cargo was conducted to generate pallet or gondola concepts. Design concepts were developed to satisfy the salient performance parameters and operational interfaces. The program to fulfill the objectives was conducted by the following tasks:

1. Parametric Study (Helicopter, Cargo, and Interface)

2. Survey of Technology (Equipment Suppliers and Commercial Operators)

3. Design Concepts (Preliminary Design)

Increased use of the helicopter in transporting vehicles, equipment, and break-bulk cargo as an externally attached load has identified the need for improved cargo-carrying support equipment.

Through the investigation and supporting analysis, the pallet concept with load acquisition points at or near base was eliminated due to its inherent flight instability and lack of structural efficiency.

OBJECTIVE

The objective of this investigation was to identify the requirements and interfaces to optimize the gondola concept and to initiate preliminary design. Subsequent to the investigation and design concept phase, the preferred concept was developed through preliminary design. The design requirements were developed to accommodate the CH-47, CH-54, and HLH to transport vehicles and equipment and break-bulk cargo as required. In addition, the gondola would provide the floor area and cubic capacity to develop full payload capacity of the three helicopters: CH-47, CH-54, and HLH. These objectives were achieved with a preferred concept which utilizes 10-ft and 20-ft gondola units which may be coupled to obtain a 40-ft gondola or used individually with a payload capacity range of 15,000 to 60,000 lb. The coupled 40-ft and individual 20-ft units are compatible with International Standard Organization geometry for land and sea operations.

REQUIREMENTS

The gondola design approach concepts were primarily predicated on the utilization of the helicopter as a principal mover and its attendant interface in the logistic supply line. While the gondola must satisfy the forward supply segment(s) of the distribution network, it should be compatible with surface modes of transportation and in contingencies with fixed-wing aircraft.

Payload Effectiveness

The gondola design(s) must provide the payload capacity and volume to satisfy each of the three helicopters. Weight should be a minimum consistent with structural requirements.

Cargo To Be Transported

Cargo to be transported will consist primarily of vehicles and equipment with secondary capability to transport break-bulk cargo.

Attachment To The Helicopter

Slings or load acquisition devices shall be used to engage four lift points located above and outside the load center of gravity (CG).

Interface Compatibility

The gondola, while principally used attached to the helicopter, should be compatible with materials handling equipment except where such equipment is capacity limited. Compatibility shall be extended to other modes of transportation consistent with MILVAN and American National Standard Institute/International Standard Organization requirements.

Logistical and Technical Requirements

Logistic impact of the gondola is such that it can be introduced at any segment of the cargo distribution network. It shall provide maximum payload capacity of the helicopter and shall be compatible with surface and sea modes of transportation through all segments of the supply network.

Structural Requirements

The gondola shall withstand the static and dynamic forces encountered from helicopter transport. Additionally, it shall withstand the forces encountered from surface modes and terminal handling.

Stability

The gondola shall have four lift point attachments above and outside the center of gravity (CG) to preclude overturning when transported by helicopter. It shall be compatible with single or multipoint suspension.

Construction

Construction shall be simple, low in cost, and resistant to rough handling and environmental degradation when operating in climatic extremes.

Modularity

Gondolas should have the capability to be joined to accommodate all three helicopters. The method of joining shall be simple and require no special tools.

HELICOPTER CHARACTERISTICS

CH-47

The CH-47B/C is a twin-rotor helicopter having internal as well as external cargo-carrying ability. The external cargo attachment is a single-point hook located at the underside of the fuselage. The power-actuated hook is on a load beam which permits lateral and longitudinal oscillations. The cargo hook fixed to the fuselage requires that personnel engage the external cargo between the load and the aircraft or use a guide pole from inside the aircraft, and this is undesirable from a personnel safety standpoint. However, we are unaware of any accidents experienced with this arrangement. The helicopter is shown in Figure 1, with data pertinent to the design of pallets/gondolas for the CH-47B/C summarized in Table 1.

CH-54

The CH-54 is a single-rotor helicopter which can utilize a cargo pod or external cargo hook/hoist available in both the A and B models. These ships are nearly identical in configuration. The B model has approximately 8,000 lb greater capacity than the A model, which for this study has the greatest impact. The ship will accept either four-point or single-point external load attachment. The four-point attachment can acquire a load with limited vertical travel with each point having either 5,000 or 8,300 lb capacity. The single-point attachment is accomplished with a cargo hook/hoist having a capacity of 25,000 lb. It is normally used to carry externally slung cargo rather than the four reel points. The reel points serve to acquire the cargo pod. The hoist has a useable length of 100 ft terminated at the hook, which is swiveled for 360° operation. Data pertinent to the design of pallets and gondolas for the CH-54A/B is summarized in Table 1.

HLH

Preliminary design of the helicopter is identified as a tandem-rotor aircraft equipped with a tandem hoist system to transport external cargo. Since the helicopter is in the preliminary design stages, complete definition of the helicopter, including the external cargo system, is not available. The principal design feature in addition to large payload capacity is the two-point hoist system. The two-point attachment should provide substantial yaw and pitch control of the load. Additionally, the hoisting capability will permit improved load acquisition since the hoisting cable would attach well below the aircraft. Data pertinent to the interface with the external pallet/gondolas is summarized in Table 1.

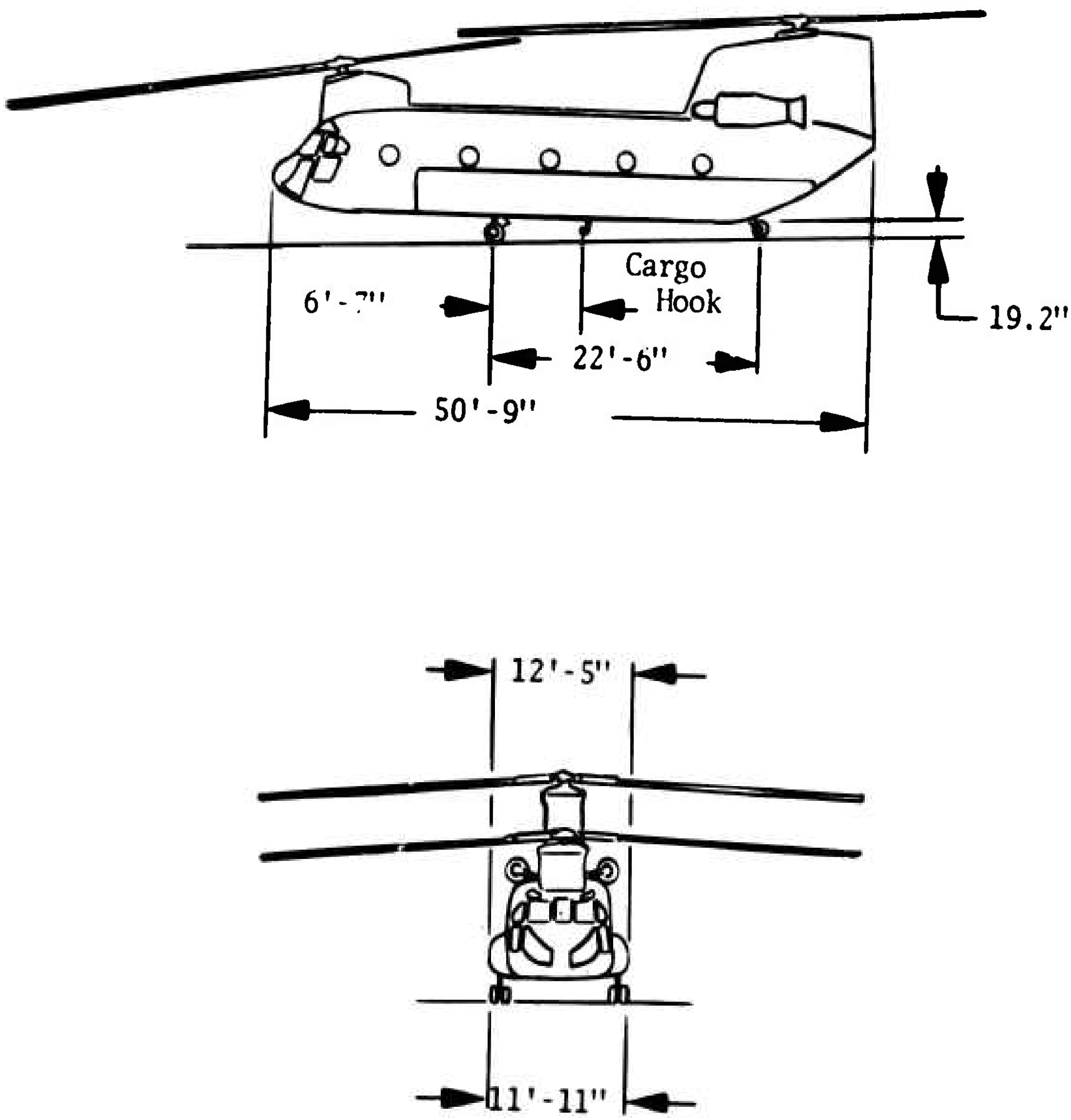

Figure 1. CH-47 Helicopter.

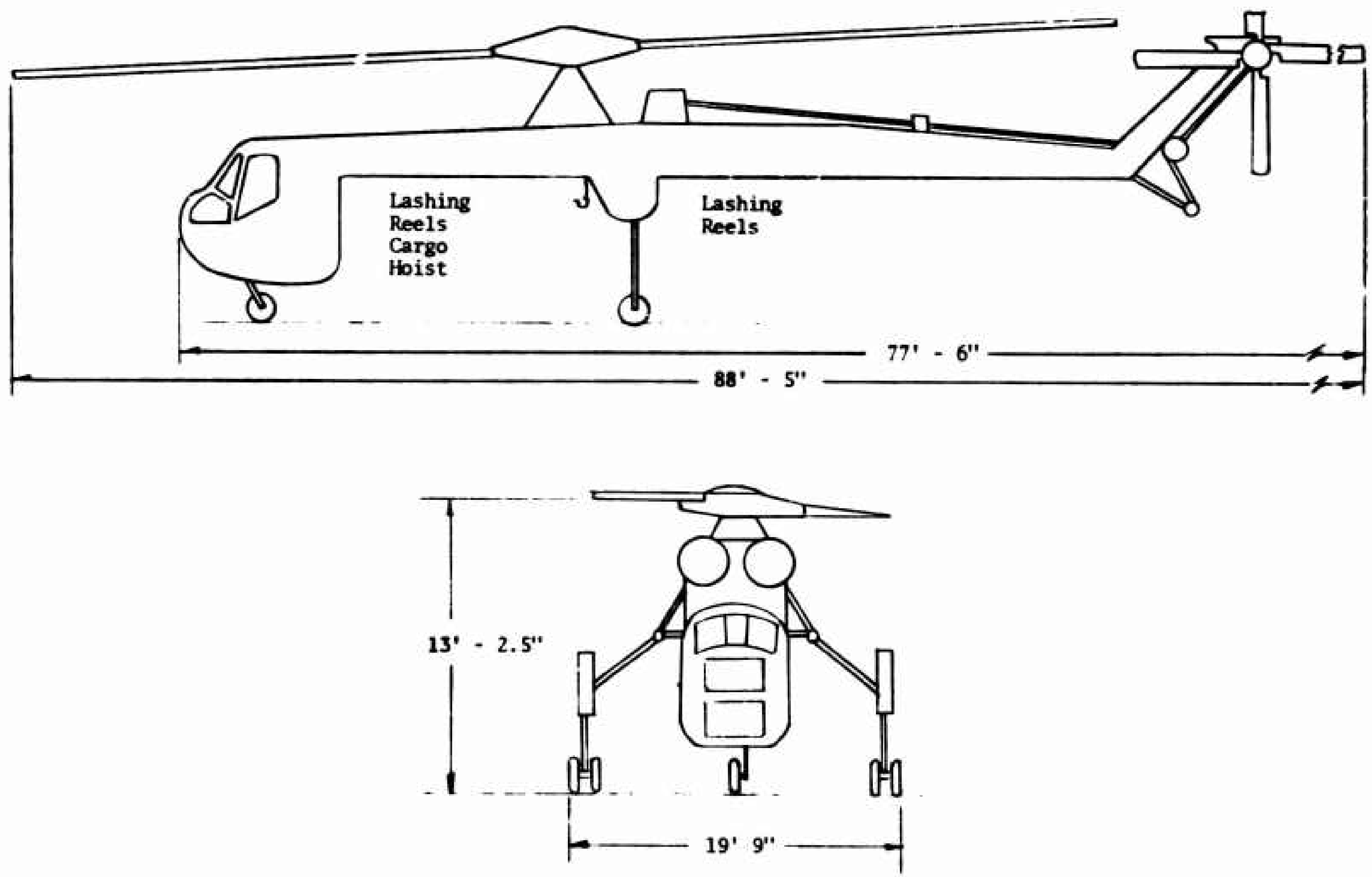

Figure 2. CH-54 Helicopter.

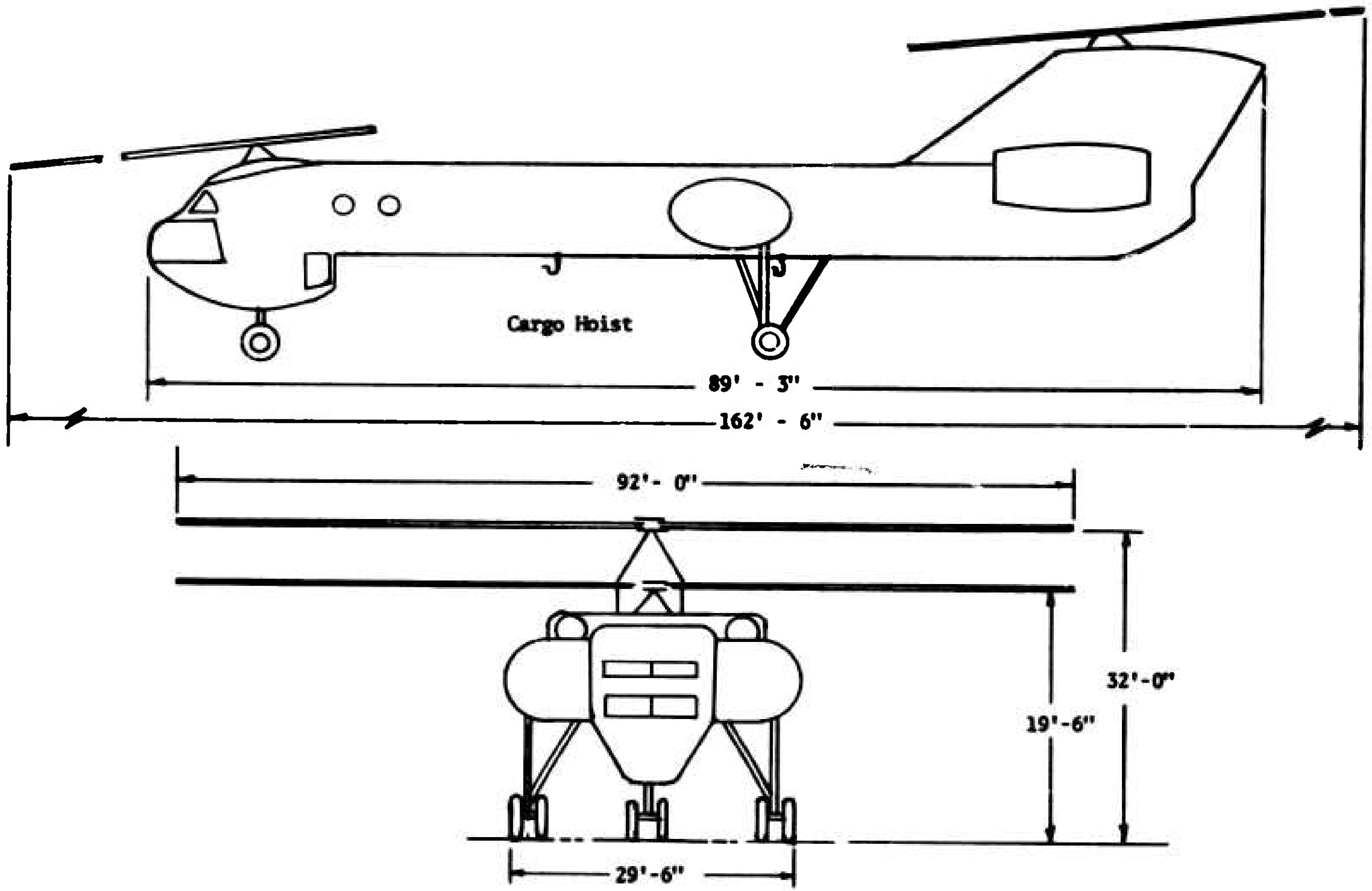

Figure 3. HLH Helicopter.

A review of the external cargo characteristics of the three helicopters suggests that they may be categorized as medium and heavy load-carrying aircraft. The CH-47 and CH-54 helicopters are nearly identical except at alternate or maximum gross weight. Since the CH-54B is weight limited to 25,000 lb by the cargo hoist, they may be considered to be in the same capacity range. The HLH is approximately double the capacity of either of the other two helicopters. The alternate capacity could exceed 70,000 lb under limited operating conditions. However, it appears that normal external cargo deliveries will be made at less than 60,000 lb. Table 1 summarizes the characteristic data for each of the three helicopters.

TABLE 1
HELICOPTER EXTERNAL CARGO CHARACTERISTICS

CHARACTERISTIC	HELICOPTER DESIGNATION				
	CH-47B	CH-47C	CH-54A	CH-54B	HLH
Payload					
Design (lb)	13,635	12,760	15,556	27,310	45,000
Maximum (lb)	19,175	19,760	19,556	27,310*	60,000
Load Factor					
Design	3	3	2.5	2.0	2.5
Maximum	2.56	2.48	2.26	2.0	2.0
Attachment--					
Single	HOOK	HOOK	HOIST OR	HOIST	--
Multiple	ø	ø	4 REELS	4 REELS	2 HOISTS
Capacity (lb)	20,000	20,000	25,000/or 5,000 ea.	25,000/or 8,300 ea.	35,000 70,000
Airspeed					
Normal Knots	150	150	100	104	140
CG Datum	331	331	336	336	unk
FWD (in)*	16.0	16.0	11.3	11.3	
AFT (in)*	5.0	5.0	3.8	3.8	

* At Gross Max.

CARGO CHARACTERISTICS

Cargo to be transported by helicopter shall include, but will not be limited to, that which is noncontainerizable; primarily, vehicles and equipment which cannot be stowed in closed containers. However, the gondola should accept break-bulk cargo for contingency missions. The principal cargo parameters which will impact design are as follows:

1. Size (length, width, and height)
2. Cube Density
3. Area Density

A listing of vehicles and equipment which might be transported as external cargo appears at the end of this section.

SIZE

Size of cargo to be handled must be considered for cube utilization. Ideally, the size of the cargo to be transported should fully utilize the cargo space of the pallet/gondola. In transporting cargo, this factor becomes quite unpredictable due to the varying package sizes. However, since the capacity of the gondola should provide for a load of 20,000, 30,000, or 60,000 lb, the cubic capacity becomes less critical for package size consideration when bulk items are being transported. Size of the pallet/gondola is not so much a function of the cargo item or package size but rather a size to develop full payload utilization of the helicopter. Since the helicopters considered herein have a capacity near 20,000 lb or greater, the size factor of items becomes secondary when compared to other interface size dimensions. While size factor of cargo may not be of primary concern, the transport of equipment and vehicles must be of concern in optimizing size. As the table indicates, the width, in some cases, is slightly greater than the nominal 8-ft highway and ocean ship cell dimension. Since these dimensions are extremes, it is possible to transport such equipment with local projections when using a porous sided gondola. Another important difference to be considered for vehicle loads is the concentration of loads from the axles. Concentrated axle or wheel loads would require considerably more structure locally. It is then advisable to design treadways or local reinforced structures for high-density axle loads. Therefore, cargo size becomes more important when transporting vehicles and outsized equipment than to accommodate standard sizes to a practical extent.

CUBE AND WEIGHT

Confined cargo delivered in containers, palletized and packaged, has a range of density from 5 to 40 lbs/cu ft. This does not exclude the possibility that heavier or lighter cargo will be experienced. However, historical data on overseas shipment since 1952 suggest that 90% of all cargo will have a cubic density of 40 lb or less. The 20-ft containers used in ocean shipment are generally accepted to have a cargo capacity of 40,000 lb. The typical cube of such a container is approximately 1100 cu ft. If the cargo space and capacity is fully utilized, the resulting cargo density would be as follows:

$$\text{Density} = \frac{40{,}000}{1100} = 36.36 \text{ lb/cu ft}$$

Data on the actual cargo densities as reported by Maritime Administration for a typical quarterly period is as follows:

North Atlantic Inbound -------------------- 22.2 lb/cu ft

North Atlantic Outbound -------------------- 19.3 lb/cu ft

Pacific Inbound --------------------------- 19.3 lb/cu ft

Pacific Outbound -------------------------- 23.4 lb/cu ft

The data[1] shows that 21.0 lb/cu ft is an approximate value for cargoes moving in both directions across the Atlantic and Pacific.[1] These densities are based on containerized cargo for the standard 8-x-8-x-20-ft container. Using the average cube density of 21.0 cu ft and available cubic capacity of 1100 cu ft, results in an average payload of 23,100 lb. This payload is approximately 3,000 lb over the capacity of the CH-47B/C and 4,000 lb below the CH-54B capacity. Experience from WW-II and the Korean engagement suggests a mean density of 22.6 lb/cu ft.[2] Since this time, equipment and other cargo have a trend toward smaller and lighter configurations and air resupply. It would appear from the data that an average cube density of 20.0 lb/cu ft would suffice for predicting cubic density of the pallet/gondola.

AREA DENSITY

The parameter that is unique to aircraft external cargo is area density (A_D), which is defined as the weight of the load (W_L) and the maximum frontal area (A_{max}) that the load can have in an attitude which might be

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[1] Berger, S., Heider, F., Lechus, J., Ralston, R., Watson, I., A CRITICAL ANALYSIS OF THE STATE OF THE ART IN CONTAINERIZATION; Control Systems Research Inc., United States Army Mobility Equipment Research and Development Center, Ft. Belvoir, VA, November 1970 AD-877259L.

[2] Wood, Charles, W., Watts, John H., Lucas, Robert M., DESIGN CRITERIA TECHNICAL CHARACTERISTICS, AND DESIGN CONCEPTS FOR AN AIR TRANSPORTABLE CONTAINER, Arthur D. Little, Inc.,; USAAML Technical Report 65-36, United States Army Aviation Materiel Laboratories, Fort Eustis, VA, June 1965 AD-619158.

expected in flight. Cargo Loads for this parameter are classified by the following types:[3]

I High-density loads,

$$W_L/A_{max} > 250 \text{ lb/ft}^2$$

II Medium-density loads,

$$250 \text{ lb/ft}^2 > W_L/A_{max} > 50 \text{ lb/ft}^2$$

III Low-density loads,

$$W_L/A_{max} < 50 \text{ lb/ft}^2$$

These types of loads are considered as bluff bodies, and with low-density loads they can induce instability, particularly if the lift points are below the CG of the load.

Aerodynamic instability is experienced when transporting low-density loads which present a relatively large drag area. Typically, this instability is experienced with empty containers which are well below the upper limits of low-density load. Therefore, the gondola should utilize an open, porous structure wherever possible. A listing of common vehicles and equipment for a road infantry division is presented in Table 2. All but one item is a Type II density load, which is favorable to external transport by helicopter.

[3] Brizinski, S.J., Karras, G. R., CRITERIA FOR EXTERNALLY SUSPENDED HELICOPTER LOADS; USAAVLABS Technical Report 71-61, U. S. Army Aviation Materiel Laboratories, Fort Eustis, VA, November 1971, AD-740772.

TABLE 2
TRANSPORTABILITY OF VEHICLE

(pg 1 of 2)

NOMENCLATURE	FIT CODE	LENGTH (IN.)	IDTH IN.)	HEIGHT (IN.)	WEIGHT GROSS (LB)	ITEMS PER GONDOLA 40	20	10
Rifle 106MM on mount M40A1	1	134	32	44	484	3	1	--
Tool Kit Org Maint NR2 Common	1	48	24	51	4376	27	13	6
TLR Amphib CGO 1/4T 2WH M100	1	109	58	43	1065	4	2	--
TLR CGO 3/4T 2WH M101	1	147	74	83	2840	3	1	--
TLR CGO 1-1/2T 2WH M105A2	1	166	83	98	5650	2	1	--
TLR CGO 1-1/2T w/ Tank Unit	1	166	83	98	5650	2	1	--
TLR Tank Water 1-1/2T 2WH M149	1	162	81	80	6040	2	1	--
TRK AMB Front Line 1/4T 4x4 M170	1	155	61	80	3763	3	1	--
TRK AMB 1/4T w/ AN/VRC-47	1	155	61	80	3763	3	1	--
TRK CGO 3/4T 4x4 M37	1	186	74	92	7200	2	1	--
TRK CGO 3/4T w/ AN/GRC-19	1	186	74	92	7200	2	1	--
TRK CGO 3/4T w/ AN/GRC-19 w/ TLR CGO 3/4T	2	327	74	92	10040	1	--	--
TRK CGO 3/4T w/ AN/GRR-5	1	186	74	92	7200	2	1	--
TRK CGO 3/4T w/ AN/GRR-5 w/ TRL CGO 3/4T	2	327	74	92	10040	1	--	--
TRK CGO 3/4T w/ AN/VRC-24	1	186	74	92	7200	2	1	--
TRK CGO 3/4T w/ AN/VRC-24 w/ TRL CGO 3/4T	2	327	74	92	10040	1	--	--
TRK CGO 3/4T w/ AN/VRC-46	1	186	74	92	7200	2	1	--
TRK CGO 3/4T w/ AN/VRC-46 w/ TLR CGO 3/4T	2	327	74	92	10040	1	--	--
TRK CGO 3/4T w/ AN/VRC-47	1	186	74	92	7200	2	--	--
TRK CGO 3/4T w/ AN/VRC-47 w/ TLR CGO 3/4T	2	327	74	92	10040	1	--	--
TRK CGO 3/4T w/ Radio TT Set AN/GRC-46	1	186	74	92	7200	2	1	--
TRK CGO 3/4T w/ TLRCGO 3/4T	2	327	74	92	10040	1	--	--
TRK CGO 1/4T 4x4 w/ WN M37	1	191	74	92	7450	2	1	--
TRK CTO 2-1/2T 6x6 LWB M35	3	263	96	112	17815	1	--	--
TRK CGO 2-1/2T M35 w/ Tank + Pump Unit	3	263	96	112	17815	1	--	--
TRK 2-12/T w/ Tank + Pump w/ TLR 1-1/2T w/ Tank	3	423	96	112	23465	1	--	--
TRK CGO 2-1/2T M35 w/ TLR CGO 1-1/2T	3	423	96	112	23465	1	--	--
TRK CGO 2-1/2T 6x6 LWB w/ WN M35	3	276	96	112	18230	1	--	--
TRK CGO 2-1/2T M35 w/ WN w/ TLR CGO 1-1/2T	3	436	96	112	23880	1	--	--

TABLE 2
TRANSPORTABILITY OF VEHICLES (pg 2 of 2)

NOMENCLATURE	FIT CODE	LENGTH (IN.)	WIDTH (IN.)	HEIGHT (IN.)	WEIGHT GROSS (LB)	ITEMS PER GONDOLA 40	20	10
TRK CGO 2-1/2T M35 w/ WN w/ TLR tank water 1-1/2T	3	432	96	112	24270	1	--	--
TRK CGO 5T 6x6 LWB w/ WN M54	3	313	97	120	29945	1	--	--
TRK CGO 5T M54 w/ WN w/ TLR Tank Water 1-1/2T	3	469	97	120	35985	1	--	--
TRK UTIL 1/4T 4x4 M151	1	132	63	71	3150	3	1	--
TRK UTIL 1/4T w/ AN/VRC-53	1	132	63	71	3150	3	1	--
TRK UTIL 1/4T w/ AN/VRC-53 w/ TLR CGO 1/4T	1	235	63	71	4215	2	1	--
TRK UTIL 1/4T w/ AN/GRC-125 w/ TLR CGO 1/4T	1	235	63	71	4215	2	1	--
TRK UTIL 1/4T w/ AN/VRC-46	1	132	63	71	3150	3	1	--
TRK UTIL 1/4T w/ AN/VRC-46 w/ TLR CGO 1/4T	1	235	63	71	4215	2	1	--
TRK UTIL 1/4T w/ AN/VRC-47	1	132	63	71	3150	3	1	--
TRK UTIL 1/4T w/ AN/VRC-47 w/ TLR CGO 1/4T	1	235	63	71	4215	2	1	--
TRK UTIL 1/4T w/ AN/VRC-49	1	132	63	71	3150	3	1	--
TRK UTIL 1/4T w/ AN/VRC-49 w/ TLR CGO 1/4T	1	235	63	71	4215	2	1	--
TRK UTIL 1/4T w/ TLR CGO 1/4T	1	235	63	71	4215	2	1	--
TRK UTIL 1/4T w/ AN/VRC-47 w/ Rifle 106MM	1	152	68	73	3465	3	1	--
TRK 1/4T w/ AN/VRC-47 w/ Rifle 106MM w/ TLR 1/4T	2	255	68	73	4530	1	--	--
TRK UTIL 1/4T 4x4 Carrier w/ Rifle 106MM	1	152	68	73	3465	3	1	--
TRK VAN SHOP 2-1/2T 6x6 M220	2	267	96	131	20435	1	--	--
TRK VAN SHOP 2-1/2T w/ Two AN/VRC-46	3	267	96	131	20435	1	--	--
TRK Wrecker MED 5T 6x6 w/ WN M62	3	349	96	110	33325	1	--	--
INTRENCH OUTFIT INF ENG SM 5-4-5180-S11	1	---	--	---	4650	--	--	--
TANK and PUMP UNIT LIQUID DISP TRK MTD	*	119	137	111	9400	--	--	--
TANK UNIT TLR MTD	1	61	72	56	4500	7	3	1

FIT CODE: 1) Can be transported by 8-x-6-x-20-ft Gondolas; 2) Can be transported by 8-x-8½-x-40-ft Gondola; 3) Can be transported if maximum width dimension is local.

NOTE. ALL ITEMS HAVE AN AREA DENSITY OF II EXCEPT FIRST ITEM WHICH IS III.

* Cannot be transported.

GONDOLA PERFORMANCE

SIZING METHODOLOGY

Sizing methodology is predicated on providing intermodal compatibility and sufficient cubic capacity to transport vehicles and equipment. Several studies have been conducted on sizing optimization for efficient use of volume payload or a composite utilization. The 8-ft gondola width allows the transporting of 75% or more of the items listed in Table 2. These results also indicate that a gondola length between 400 and 500 in. would have more utility in transporting tactical vehicles and equipment than a shorter gondola. Therefore, it would appear that a wider and longer gondola would be best suited to the HLH than the medium helicopter. Additionally, the smaller gondola would transport the break-bulk items by realizing more efficient distribution in forward areas.

Load Capacity

Pallet/gondola performance can then be identified from the helicopter capacity and the cargo to be transported. As shown in Table 2, the two medium-lift helicopters have a maximum payload capability near 20,000 lb, with the CH-54B at 27,310 lb, and the HLH at 60,000 lb. To provide a 20,000-lb-capacity gondola for a helicopter load factor of 2.56 requires a structure that would carry a load which is near the capacity of the CH-54B (26,087 vs. 27,310).[4] This is 95% capacity of the CH-54B helicopter. From this aspect it does not appear feasible to have separate pallets/gondolas for the CH-47 and CH-54 aircraft.

The HLH aircraft has approximately threefold the capacity of the other helicopters under consideration. This increased capacity suggested a significantly greater volume than required for the CH-47 and CH-54. It appears that the normal operable capacity for this ship is 60,000 lb with a load factor of 2.0. Therefore, considering both load capacity and dynamic load factor of the helicopters suggests two sizes of gondolas.

Cubic Capacity

Cubic capacity of the gondola should provide sufficient volume such that the helicopter will be operating at or near payload capacity most of the time. Previous studies of confined cargo suggest that a cubic density of 21.0 lb/cu ft is average. Since trends are to lighter and smaller equipment and packaging, a cube density of 20.0 lb/cu ft will be used to predict the volume of the various payload capacities. The resulting volume for a

[4] Huebner, Walter E., DESIGN GUIDE FOR LOAD SUSPENSION POINTS, SLINGS, AND AIRCRAFT HARD POINTS; USAAMRDL Technical Report 72-36, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA, July 1972, AD-747814

20,000-lb load would, therefore, be 1,000 cu ft. For a 60,000-lb load, a volume of 3,000 cu ft is required. The cube root of each of these volumes is 10 ft and 14,425 ft respectively. It is immediately obvious that these dimensions are impractical to interface with other modes of transportation and are both damaging and cumbersome to stack break-bulk cargo to 14.4 ft heights.

If we limit the width and the height to 8-ft for intermodal transportability, we arrive at the following lengths:

$$L = V \div A$$

$$L = V/A$$

$$L = 1{,}000 \div 64 = 15.625 \text{ ft } (20{,}000 \text{ lb/load})$$

$$L = 3{,}000 \div 64 = 46.88 \text{ ft } (60{,}000 \text{ lb/load})$$

However, if we allow tare width for the side rails, floor, and transverse bracing, the internal dimensions of an 8-x-8-x-20-ft gondola becomes 7.0 x 7.3 x 19.489, yielding 1,000 cu ft. On the other hand, if we permit the height of the larger gondola to increase to 9.5 ft, the length becomes 40.93 ft. These dimensions then approximate the standard 20- and 40-ft containers. If the sides and top permit local protuberances, these lengths would suffice. Additionally, the cube utilization becomes more efficient for larger volumes. This fact becomes particularly true when carrying equipment and vehicles, much of which would have a higher average density. Cargo at 30 lb/cu ft would be satisfied by an 8-x-8.5-x-40-ft gondola which would have a net volume slightly over 2,000 cu ft. Therefore, it is concluded that some of the pallet/gondola concepts consider a cubic configuration within these envelope dimensions. Incidental to the 8-x-20-ft or 8-x-40-ft plan area is the fact that the standard MAC pallet would accept the gondola floor. Planned utilization of the larger gondola would experience a density such that it would rarely be cube limited.

Area Density

Area density is defined as the ratio of gross gondola weight over the maximum frontal (front or side) area. Suspended loads from single-point helicopter attachment tend to rotate such that the maximum cross-sectional area of the cargo will be perpendicular to the airstream. The area density ratio is a measure, or indication, of the stability of the suspended cargo. Area density as the relationship of height (H), width (W), and length (L) are varied, maintaining a constant volume, is shown in Appendix B. It is seen that area density is a maximum for a cube where H = W = L. The maximum value is also applicable for all cases where the height is less than the minimum base dimension. Therefore, the most stable gondolas are those whose height is equal to or less than the minimum base dimension.

Payload Effectiveness

Gondola weight ratios (tare weight/payload capacity) for cubic and oblong gondolas are discussed in Appendix B. Cargo load is that experienced in transporting vehicles, equipment, and break-bulk cargo. As expected, tare weight as a ratio of payload decreases as cargo density increases. Additionally, the area density increases with improved stability. Optimum sizing to minimize tare weight is achieved with cubic gondolas between 5 and 7 ft with welded aluminum alloys. However, the size is insufficient to achieve the desired payload capacity. By using bolted connections, the trend reverses as cube increases. Additionally, an over-cube (oblong) gondola shows a tare weight ratio reduction as the load exceeds 30,000 lb.

A component breakdown of structural members as a function of weight, cargo, density, and load is presented in Appendix B.

This sizing methodology based on area density would not provide sufficient cubic capacity for any of the helicopters. The single-point suspension which allows the load to fly broadside would suggest a cube to achieve maximum area density. This would provide a 10-x-10-x-10-ft gondola to satisfy a requirement of 1,000 cu ft. Too frequently a stacking height of 10-ft is undesirable for vertical crushing loads and encumbers loading the gondola. Similarly, the 10-ft width severely limits shipment by highway, ocean, and some aircraft. Therefore, the 10-ft-high and 10-ft-wide dimensions do not interface with other modes of transportation. Reducing the height and width to 8-ft respectively satisfies the intermodal capability. However, the length would increase to approximately 20-ft.

Assuming a 20,000-lb payload, the area density would decrease from 200 lb/ft^2 (for a 10-ft cubic) to 125 lb/ft^2. This area density would appear to tow with minimum trail angle as presented in the following section on Stability.

A comparative analysis of a cubic gondola and oblong one (base length exceeds width) shows that tare weight is increased by slightly more than 1/2% over a cubic gondola for a 20,000-lb capacity. However, a gondola for 50,000 lb becomes more efficient when configured with an 8-x-40-ft floor plan. Figure B-10 demonstrates that as length increases, oblong gondolas become more efficient than cubic configurations.

STABILITY

Stability of helicopter externally transported cargo is analyzed from the following considerations:

Towing Stability

System Excitation "Vertical Bounce"

System excitation or vertical bounce is a phenomenon whereby the airframe body bending and rotor RPM become sympathetic. This excitation is experienced when an external force is imposed on the helicopter such as a slung load. The second stability factor is the aerodynamic characteristics of a bluff body when towed.

TOWING STABILITY

The transportation of large cargoes by helicopter introduces several load/stability problems that reduce flight speed and affect control of the helicopter.

One of these problems occurs when large oblong containers (freight, gondolas, loaded pallets, etc.) are suspended under a helicopter with a single-point suspension. This type of load will rotate until it presents the largest frontal area perpendicular to the direction of flight and, therefore, creates the highest possible drag.[5]

Rotational or yaw instability can be reduced by proper aerodynamic shape, the addition of drogue chutes or vertical stabilizers, or additional attachment points on the helicopter. By far, the most effective is two or more attachment points on the helicopter. Wind tunnel tests[6] conducted on attachment points suggest that a longitudinal separation of 48.0 in. or more is an improvement. This approach to yaw and attendant pitch control of the load appears to be the most positive.

As the drag forces become significant, the resulting force vector (F_{Drag} F_{WT}) are at an angle and, therefore, no longer act through the center of gravity, thus creating additional aircraft stability and control problems for the pilot. Therefore, it is imperative that large cargoes be properly aligned to minimize the drag forces. A comparison is presented for four large cargo profiles, 8-x-8-x-20-, -30, -40, and -50-ft containers, flown

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[5] Lehmann, Maurice John William; Captain, AERODYNAMIC CHARACTERISTICS OF NON-AERODYNAMIC SHAPES, Air Force Institute of Technology, Wright-Patterson Air Force Base, June 1968

[6] Gabel, Richard, Wilson, Gregory; TEST APPROACHES TO EXTERNAL SLING LOAD INSTABILITIES, Vertol Division, The Boeing Co.

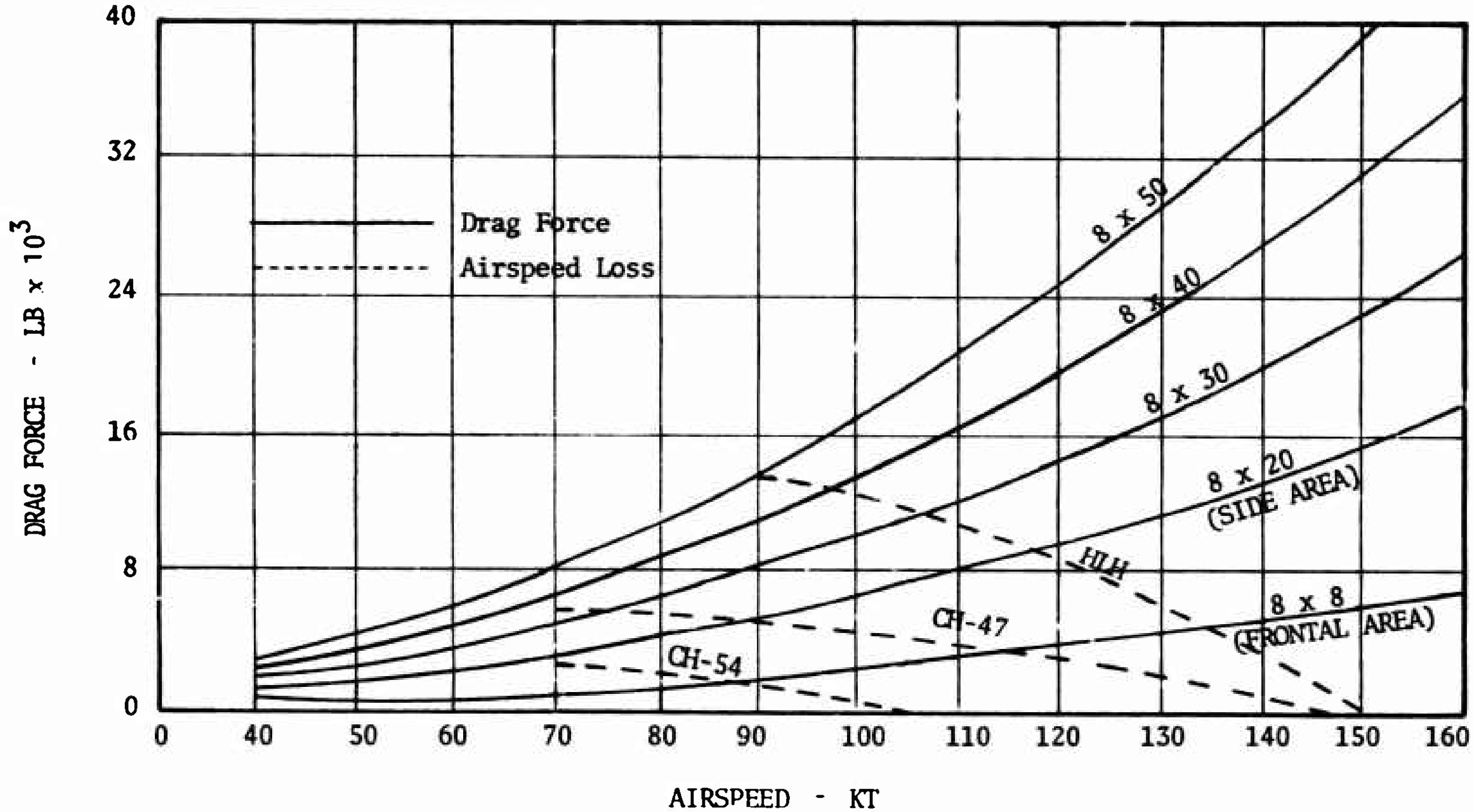

Figure 4. Load Profile Drag Forces.

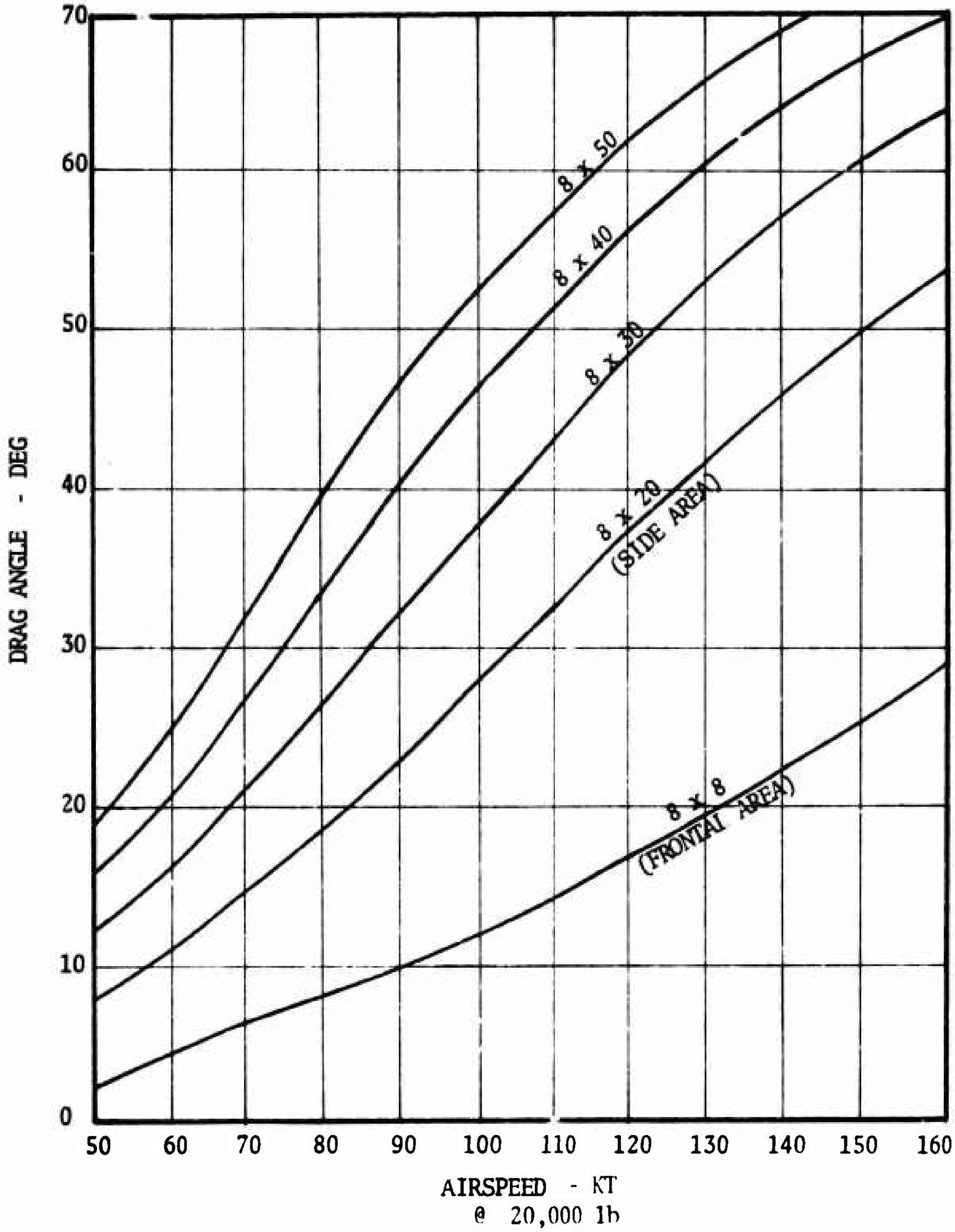

Figure 5. Minimum Drag Angles.

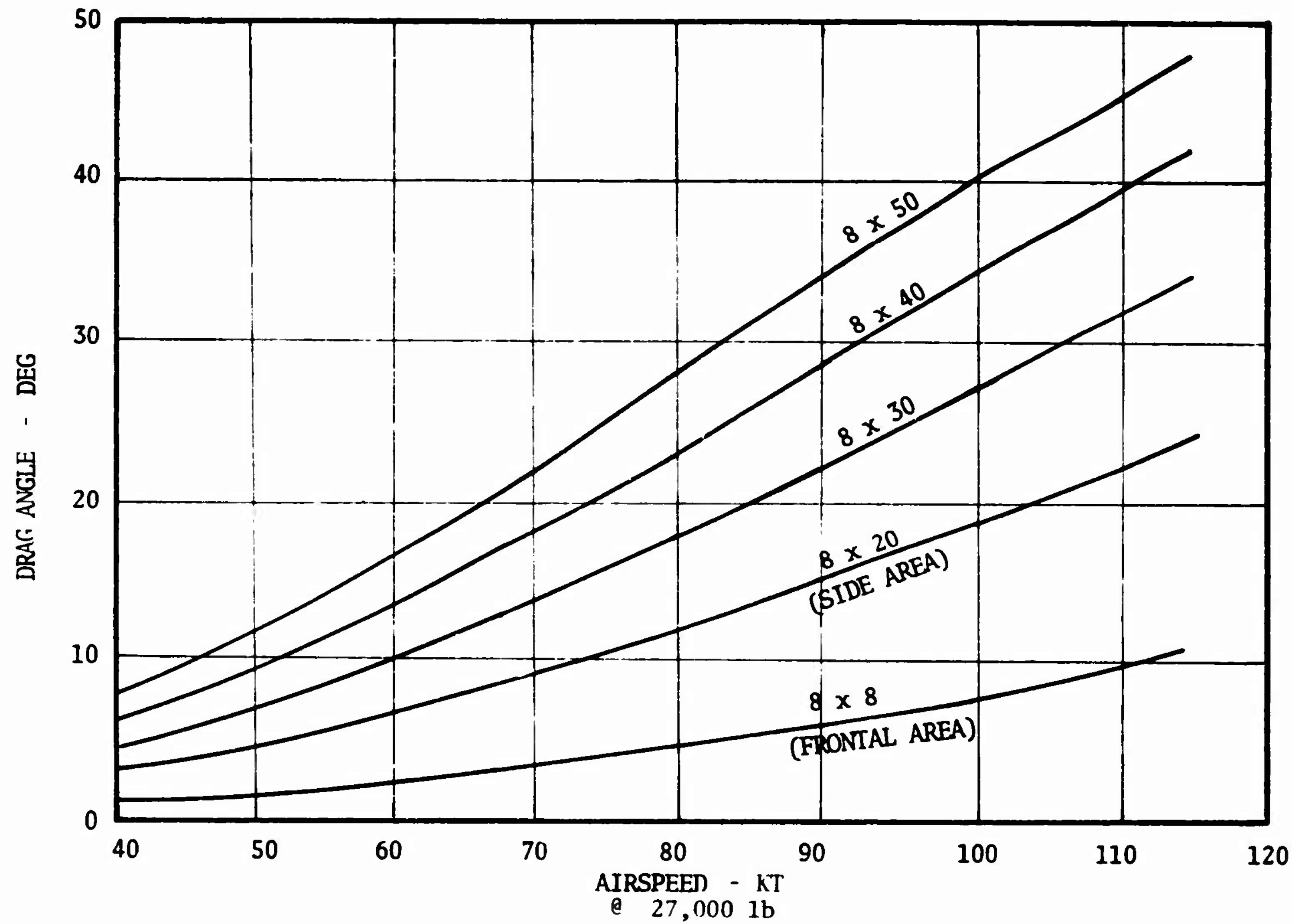

Figure 5. (continued).

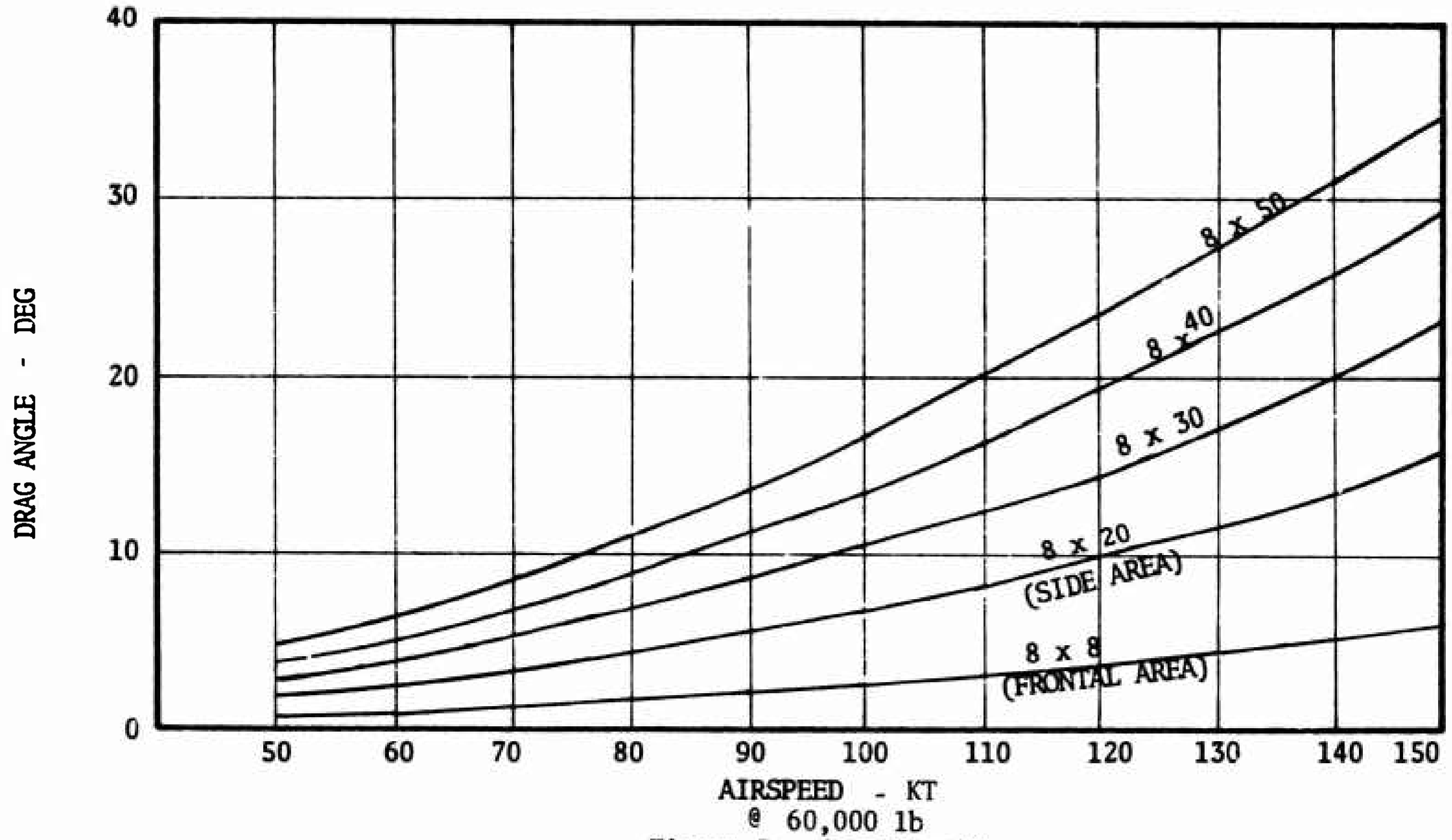

Figure 5. (continued).

at sea level, at airspeeds from zero to 160 knots, and positioned parallel to and perpendicular to the airstream. (See Figures 4 and 5.)

$F_D = D_C q A$	Drag Force
$C_D = 1.28$	Flat Plate Coefficient of Drag
$A = (H)\ (W)$ or $(H)\ (L)$	Flat Plate Area Perpendicular to Airstream
$q = 1/2\ \rho\ V^2$	Dynamic Pressure
$\rho = .00237$ slugs/ft^2	Density of Air

It is shown that an unrestrained 8-x-8-x-20-ft load will produce drag loads of 2.5 times those drag loads which would result from a restrained load. The increased load is 6.25 for an 8-x-8-x-50-ft load.

The cargo drag angle is a function of the profile drag force and the load weight,

$$\left(\Theta = \tan^{-1} \frac{F_D}{WT} \right)$$

The angle approaches 90^o as the weight of the container approaches zero. The minimum possible drag angle for helicopter maximum payload is shown; at nominal airspeeds, these angles become large and will necessitate the utilization of longer than desired pendants to prevent helicopter-cargo impacts. Long pendants create additional vertical control stability problems. Therefore, the advantages of rotational cargo restraint are obviously desirable (side load angles were included for the CH-54 and HLH even though these helicopters employ a two-point or four-point hoist system which partly restrains rotation).

Vertical Drag

A second load/stability problem is the "downwash" loading on large "planform" cargoes. This additive loading on the cargo profile requires that some of the total helicopter lift capacity be used to counteract this load, thus reducing the useful helicopter lift capacity. The helicopter can reach a large enough forward velocity (when the cargo drag angle is sufficiently increased to swing the cargo out of the "downwash" airstream) to eliminate this additional load, but this does not help much since the loading is always present at the load acquisition and load release times.

Experimental "downwash" measurements were obtained by a joint US and UK test effort at Boscombe Downe, England, in May/June 1971.[7] These tests were with a large "planform" cargo (12-x-52-ft bridge). The results indicate that "downwash" loading can be predicted by,

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[7]Bradley, J., Toms, G., BRIDGE EMPLACEMENT TRIALS - PHASE II USING CH-47A AND CH-54A HELICOPTERS; Aeroplane and Armament Experimental Establishment, Boscombe Down, United Kingdom.

$$F = P_D \{1 - .0006 (H_{DH} + H_{HC})^2\} \{A_C - \frac{A_{H/C}}{2}\}$$

H_{DH} is a fixed distance for each helicopter.

H_{HC} has a minimum value for each size cargo, for each helicopter, in order to maintain the 30-degree maximum load angle required for most helicopters.

CH-47

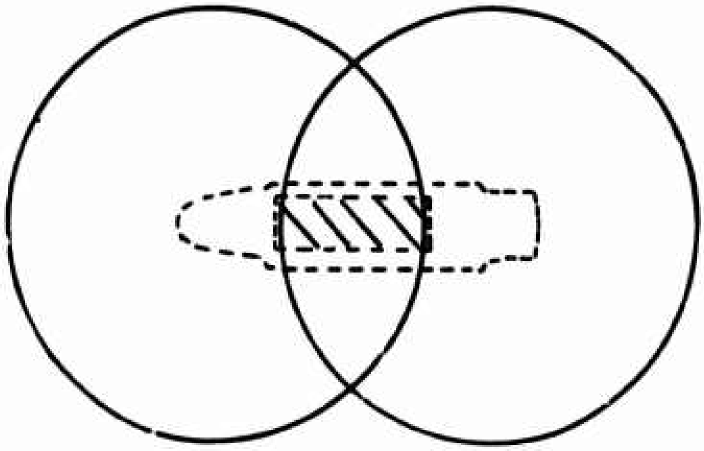
A single-point suspension system is used in this helicopter. Therefore, containers are analyzed in the fore-and-aft and sideways orientations. Container sizes 8-x-8-x-20, 30, 40, and 50 are analyzed, and the 8-x-8-x-20 and 8-x-8-x-50 sizes are illustrated. It is shown that the payload capacity "lost" is appreciable. Lengthening the suspension cable in order to reduce these "downwash" loads, however, serves only to increase other stability problems.

TABLE 3
CH-47 CARGO CONTAINERS ORIENTATED FORE AND AFT

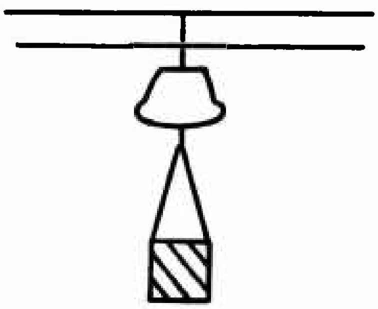
CARGO (ft)	A_C	H_{HC}	H_{DH}	P_D	$A_{H/C}$	F	MAX PAYLOAD (lb)	USEABLE PAYLOAD (lb)
8 x 8 x 20	160	17.3	13	5.84	160	441	20,000	19,559
8 x 8 x 30	240	26.0	13	5.84	240	637	20,000	19,363
8 x 8 x 40	320	34.6	13	5.84	320	807	20,000	19,193
8 x 8 x 50	400	43.3	13	5.84	400	946	20,000	19,054

TABLE 4
CH-47 CARGO CONTAINERS ORIENTATED SIDEWAYS

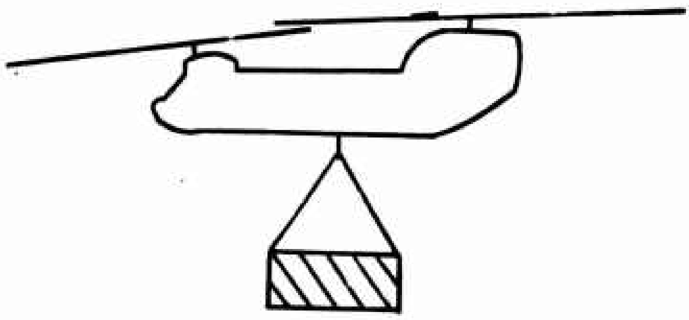
CARGO (ft)	A_C	H_{HC}	H_{DH}	P_D	$A_{H/C}$	F	MAX PAYLOAD (lb)	USEABLE PAYLOAD (lb)
8 x 8 x 20	160	17.3	13	5.84	99	610	20,000	19,390
8 x 8 x 30	240	26.0	13	5.84	99	1011	20,000	18,989
8 x 8 x 40	320	34.6	13	5.84	99	1365	20,000	18,635
8 x 8 x 50	400	43.3	13	5.84	99	1658	20,000	18,342



CH-47 TRANSPORTING 8-x-8-x-20-FT CARGO CONTAINER
ORIENTATED FORE AND AFT (PLAN VIEW)

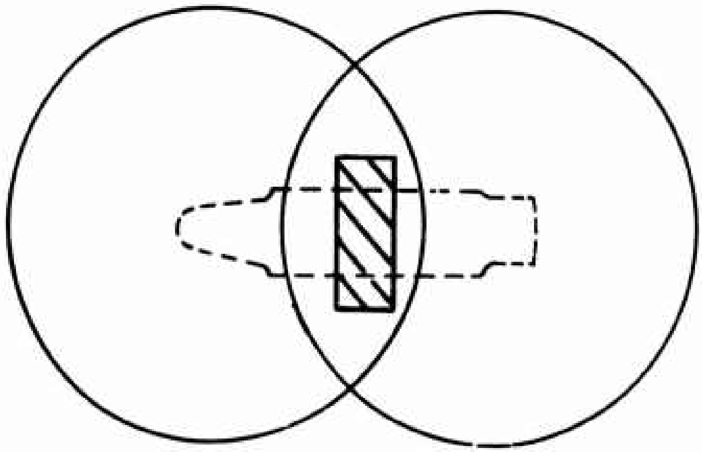


CH-47 TRANSPORTING
8-x-8-x-20-FT
CARGO CONTAINER
ORIENTATED FORE AND AFT
(FRONT VIEW)

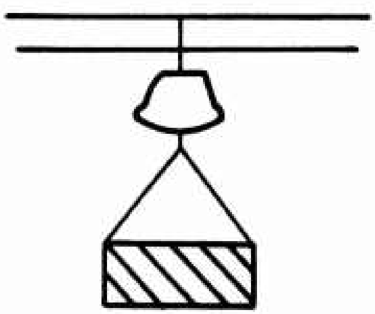


CH-47 TRANSPORTING 8-x-8-x-20-FT
CARGO CONTAINER
ORIENTATED FOR AND AFT
(SIDE VIEW)

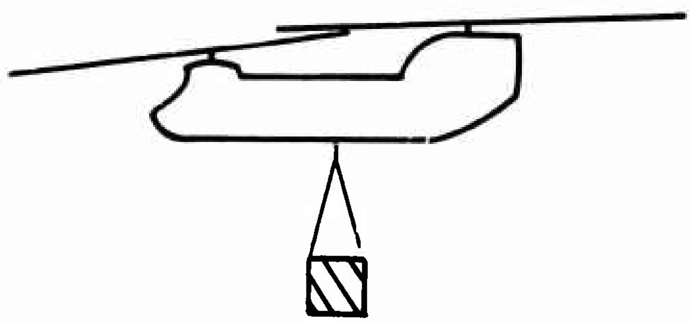
Figure 6. Vertical Drag CH-47.



CH-47 TRANSPORTING 8-x-8-x-20-FT CARGO CONTAINER
ORIENTATED SIDEWAYS (PLAN VIEW)



CH-47 TRANSPORTING
8-x-8-x-20 FT
CARGO CONTAINER
ORIENTATED SIDE WAYS
(FRONT VIEW)



CH-47 TRANSPORTING 8-x-8-x-20-FT
CARGO CONTAINER
ORIENTATED SIDEWAYS
(SIDE VIEW)

Figure 6. Continued.

DEFINITIONS

A_D	Area of Blade(s) Disk
A_H	Area of Helicopter
$A_{D/H}$	Area of Helicopter Covered by Disk
A_C	Area of Cargo
$A_{D/C}$	Area of Cargo Covered by Disk
$A_{H/C}$	Area of Cargo Covered by Helicopter
H_{DH}	Height from Disk to Cargo Hook to Cargo
H_{CG}	Height from Cargo to Ground
P_D	Disk Pressure

CH-47

$A_D = 2 \frac{\pi}{4} (60)^2 = 5{,}655 \text{ ft}^2$

$A_H = 33 (12.4) + 17.75 (9) = 569 \text{ ft}^2$

$A_{DH} = 569 \text{ ft}^2$

$H_{DH} = 13 \text{ ft}$

$WT = 20{,}000 \text{ lb}$

Payload (max) = 13,000 lb

$DL_{max} = (20{,}000 + 13{,}000)/5{,}655 = 5.84 \text{ lb/ft}^2$

$V_{max} = 160 \text{ kt}$

CH-54

This helicopter is considered as a single-point suspension system. Therefore, all cargo containers should be orientated fore and aft. Container sizes 8-x-8-x-20, 30, 40, and 50 are again analyzed and the 8-x-8-x-20-ft and 8-x-8-x-50-ft containers are again illustrated. This system also has an appreciable "lost" payload capacity. The percentage of payload capacity lost is greater for the CH-54 than for the CH-47 due to: (1) higher disk loading for the CH-54 and (2) cargo containers closer to the blades due to a 15.625-ft spread between hoist points.

TABLE 5
CH-54 CARGO CONTAINERS ORIENTATED FORE AND AFT

CARGO (ft)	A_C	H_{HC}	H_{CH}	P_D	$A_{H/C}$	F	MAX PAYLOAD (lb)	USEABLE PAYLOAD (lb)
8 x 8 x 20	160	3.8	7.5	10.31	140	921	25,000	24,079
8 x 8 x 30	240	12.4	7.5	10.31	208	1369	25,000	23,631
8 x 8 x 40	320	21.1	7.5	10.31	272	1804	25,000	23,196
8 x 8 x 50	400	29.8	7.5	10.31	331	2216	25,000	22,784

CH-54

$A_D = \frac{\pi}{4} (72)^2 = 4,072 \text{ ft}^2$

$A_H = 36 (7) + 1/2 (7 + 1.5) 33 = 392 \text{ ft}^2$

$A_{D/H} = 36 (7) + 1/2 (7 + 2.7) 26 = 378 \text{ ft}^2$

$H_{DH} = 7.5 \text{ ft}$

WT = 21,500 lb

Payload (max) = 20,500 lb

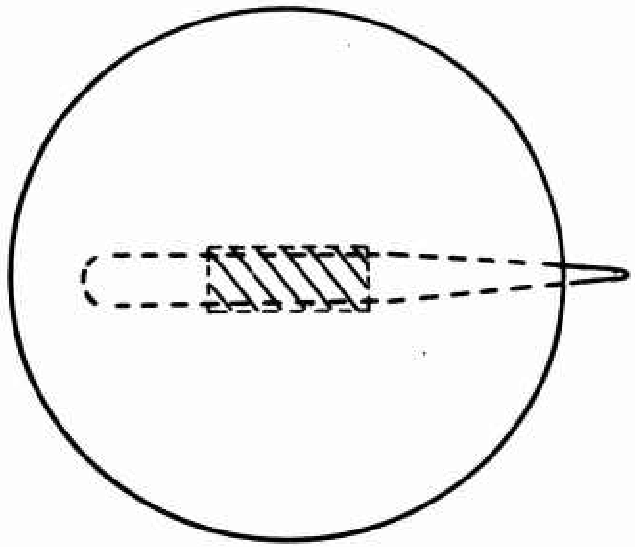
$D_{L_{max}} = (21,500 + 20,500)/4,072 = 10.31 \text{ lb/ft}^2$

$V_{max} = 115 \text{ kt}$

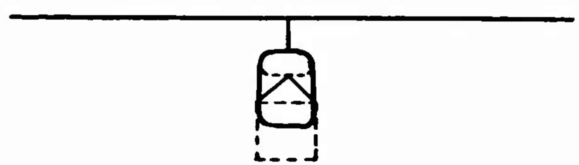
15.625 ft between hoists

HLH

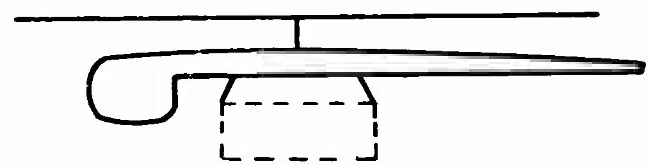
This helicopter also has a dual-point suspension. The same containers considered for the other helicopters are again analyzed in the fore and aft orientation. The "lost" payload capacity is shown in Table 6.



CH-54 TRANSPORTING 8-x-8-x-20-FT CARGO CONTAINER ORIENTATED FORE AND AFT (PLAN VIEW)

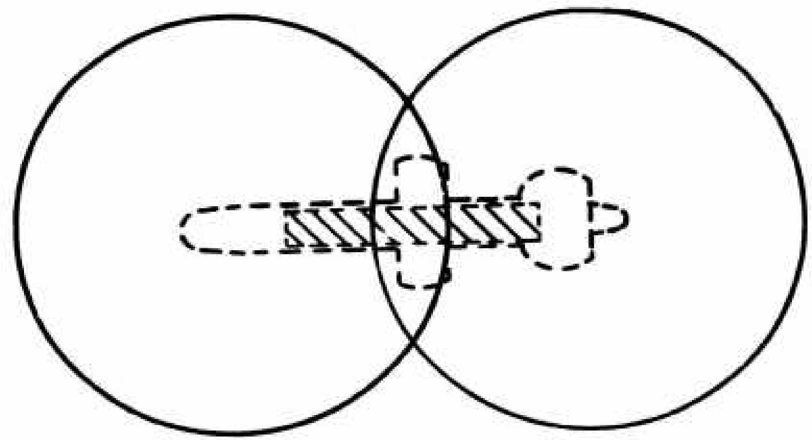


CH-54 TRANSPORTING 8-x-8-x-20-FT CARGO CONTAINER ORIENTATED FORE AND AFT (FRONT VIEW)

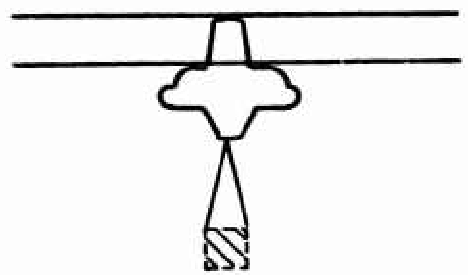


CH-54 TRANSPORTING 8-x-8-x-20-FT CARGO CONTAINER ORIENTATED FORE AND AFT (SIDE VIEW)

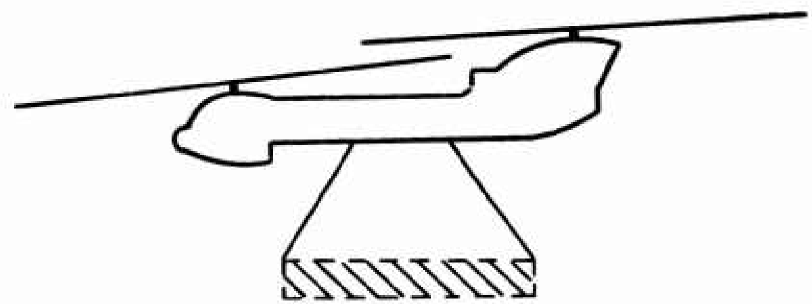
Figure 7. Vertical Drag CH-54.



HLH TRANSPORTING 8-x-8-x-50-FT CARGO CONTAINER
ORIENTATED FORE AND AFT (PLAN VIEW)



HLH TRANSPORTING 8-x-8-x-50-FT
CARGO CONTAINER
ORIENTATED FORE AND AFT
(FRONT VIEW)



HLH TRANSPORTING 8-x-8-x-50-FT
CARGO CONTAINER
ORIENTATED FORE AND AFT
(SIDE VIEW)

Figure 8. Vertical Drag HLH.

TABLE 6
HLH CARGO CONTAINERS ORIENTATED FORE AND AFT

CARGO (ft)	A_C	H_{HC}	H_{DH}	P_D	$A_{H/C}$	F	MAX PAYLOAD (lb)	USEABLE PAYLOAD (lb)
8 x 8 x 20	160	1.7	18	9.03	160	706	60,000	59,295
8 x 8 x 30	240	10.4	18	9.03	240	1031	60,000	58,969
8 x 8 x 40	320	19.1	18	9.03	320	1325	60,000	58,675
8 x 8 x 50	400	27.7	18	9.03	400	1580	60,000	58,420

$A_D = 2 \frac{\pi}{4} (96)^2 = 13.295 \text{ ft}^2$

$A_H = 1{,}100 \text{ ft}^2$

$A_{D/H} = 1{,}110 \text{ ft}^2$

$H_{DH} = 18 \text{ ft}$

WT = 64,000 lb

Payload (max) = 56,000 lb

$D_{L_{max}} = (64{,}000 + 56{,}000)/13{,}295 = 9{,}103 \text{ lb/ft}^2$

$V_{max} = 150 \text{ kt}$

18 ft between hoists

LIFT POINT STABILITY

In addition to yaw and pitch angle, oscillatory instability is a condition which may cause the load to overturn. This overturning or "flipping" due to drag forces can be eliminated by placing the lift point(s) above the CG.[4] The following analyses consider conditions under which this instability may occur and the corrective action necessary to eliminate it. It demonstrates that a load-bearing pallet with attachment points below the CG could overturn, eliminating pallets as a viable concept. Therefore, a design constraint of providing lift points above the CG must be provided. Having lift points above the CG is the singularly most distinguishing characteristic between a pallet and gondola. Providing elevated lift points requires they be supported to react both the lifting loads and the lateral and transverse loads induced by the sling angle. Although the gondola is penalized with the added weight of the upper support structure, its overall weight efficiency is comparable to a simple load-bearing pallet with lift points in the base. An example of this is the monocoque pallets in Reference 8. These pallets, as well as those produced for NASA, were as heavy as, or heavier than, the trussed gondolas proposed herein. The addition of elevated load points to a pallet base structure adds little or no additional weight to the gondola.

There are three forces acting on a pallet:

1. Weight--Effective weight is a function of the dynamic load factor which is vibratory, i.e., weight effect can be reduced to zero when the load rebounds.

$$W_{EFF} = W_T - \{DLF-1\}\ W_T$$

2. Drag--The flat plate drag coefficient is 1.28.

3. Lift--The ~~ c plate lift coefficient is .60.

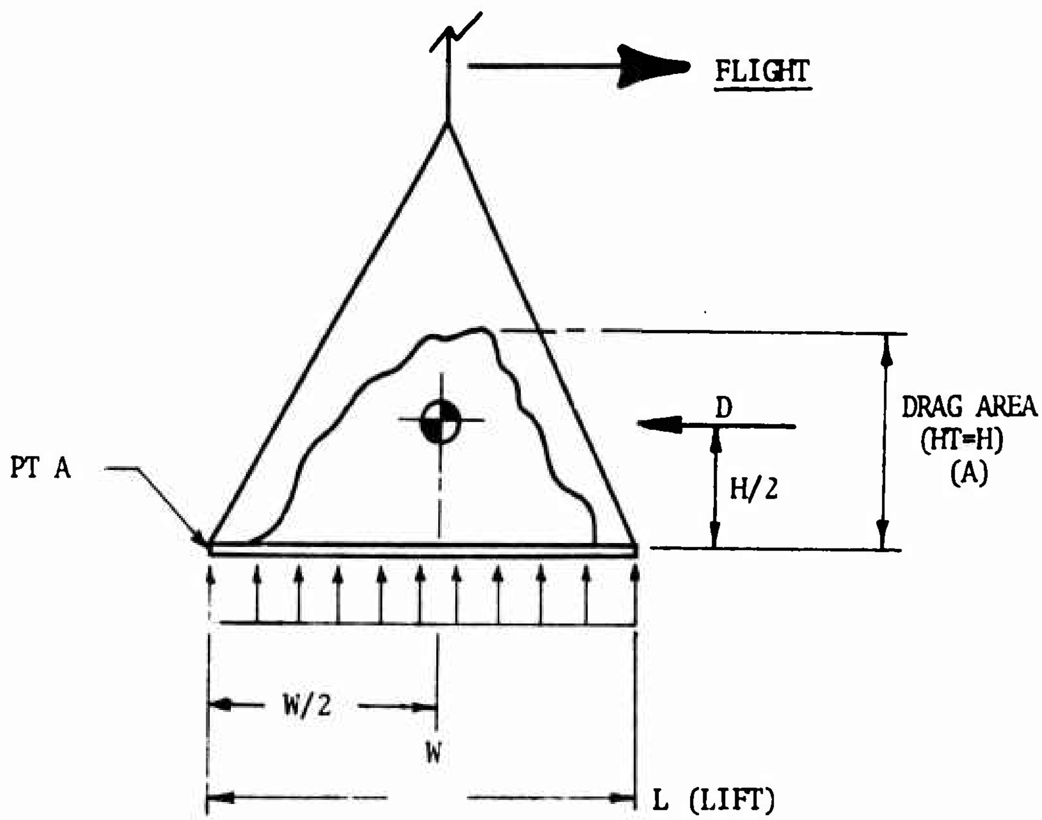


Figure 9. Pallet Instability.

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[8] Krolikiewicz, DESIGN, DEVELOPMENT, FABRICATION, AND TESTING OF SMALL AND LARGE LOAD-BEARING PALLETS FOR THE CH-54 "FLYING CRANE" HELICOPTER; Brooks & Perkins Inc., USAAVLABS Technical Report 68-71, U. S. Army Aviation Materiel Laboratories, Fort Eustis, VA, OCT 1968, AD-680283

A simple case will be illustrated assuming:

1. Cargo is essentially cubic (optimum shape)
2. CG is at center of cube
3. A_D = 50 (area density)
4. DLF = 1.0 (dynamic load factor) (stable condition)

The effect of varying CG, A_D, and DLF is presented in Figure 10.

$A_D = 50 = \frac{WT}{A}$

$W_T = 50\ A$

$H/2 = 1/2\ A$ for cube

and $W = A$ and $W/2 = 1/2\ A$

(drag area is equal to lift area)

Drag Force = 1.28 A q

Lift Force = .6 A q

Weight Force = 1.0 W_T = 50 A

Summing forces about point A.

$\Sigma M_A = 0$

$M_W = M_D + M_L$

$50\ A \frac{A}{2} = 1.28\ A\ q \frac{A}{2} + .6\ A\ q \frac{A}{2}$

$50\ A = 1.88\ A\ q$

$q = 50/1.88 = A\ q$

$q = 1/2\ \rho\ V^2 = .00255\ V^2$ (MPH at sea level)

$.00255\ V^2 = 26.6$

$V = 102.15$ MPH

Therefore, the pallet, in this case, will flip over at or above flight speeds of 102.15 mph.

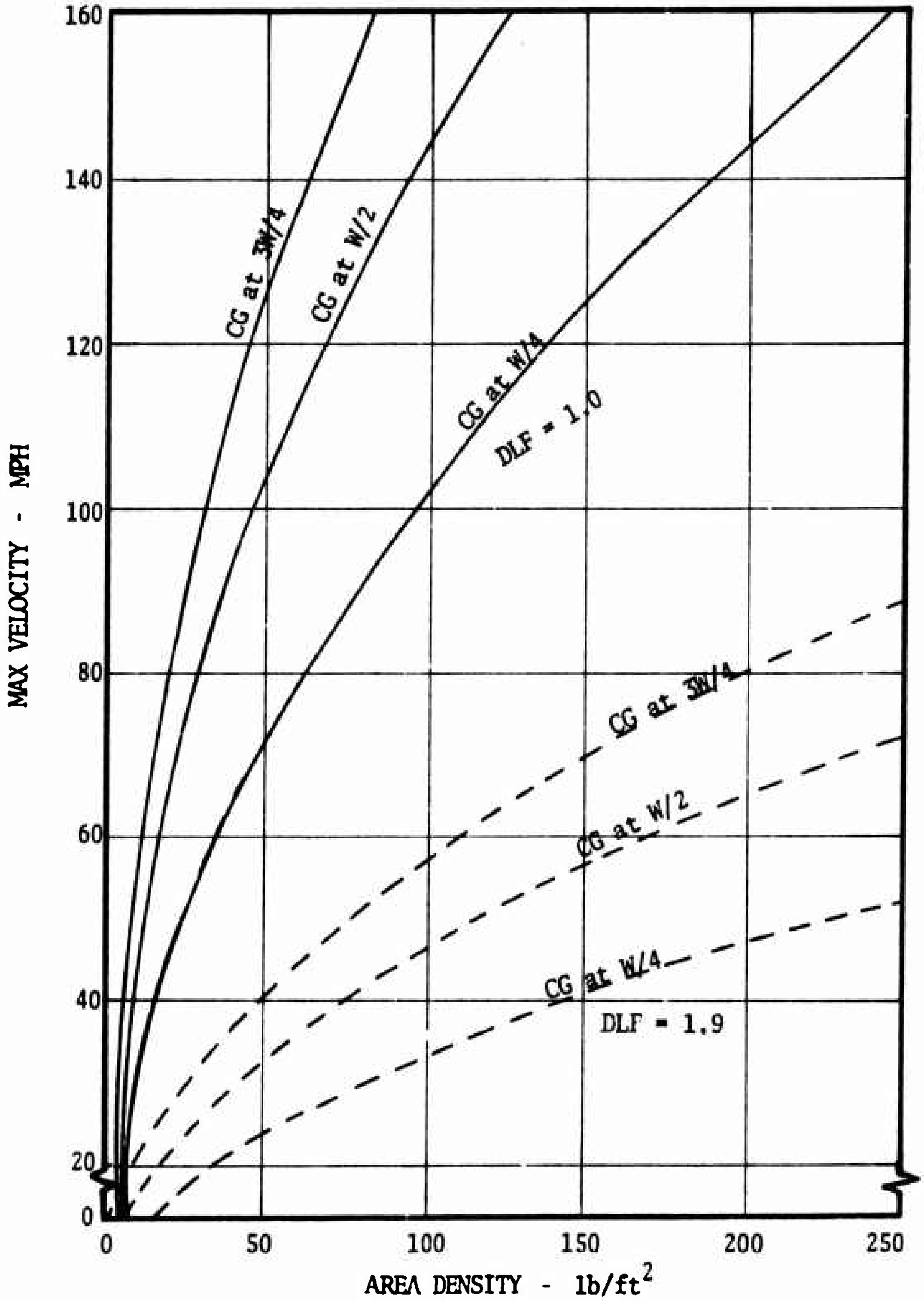
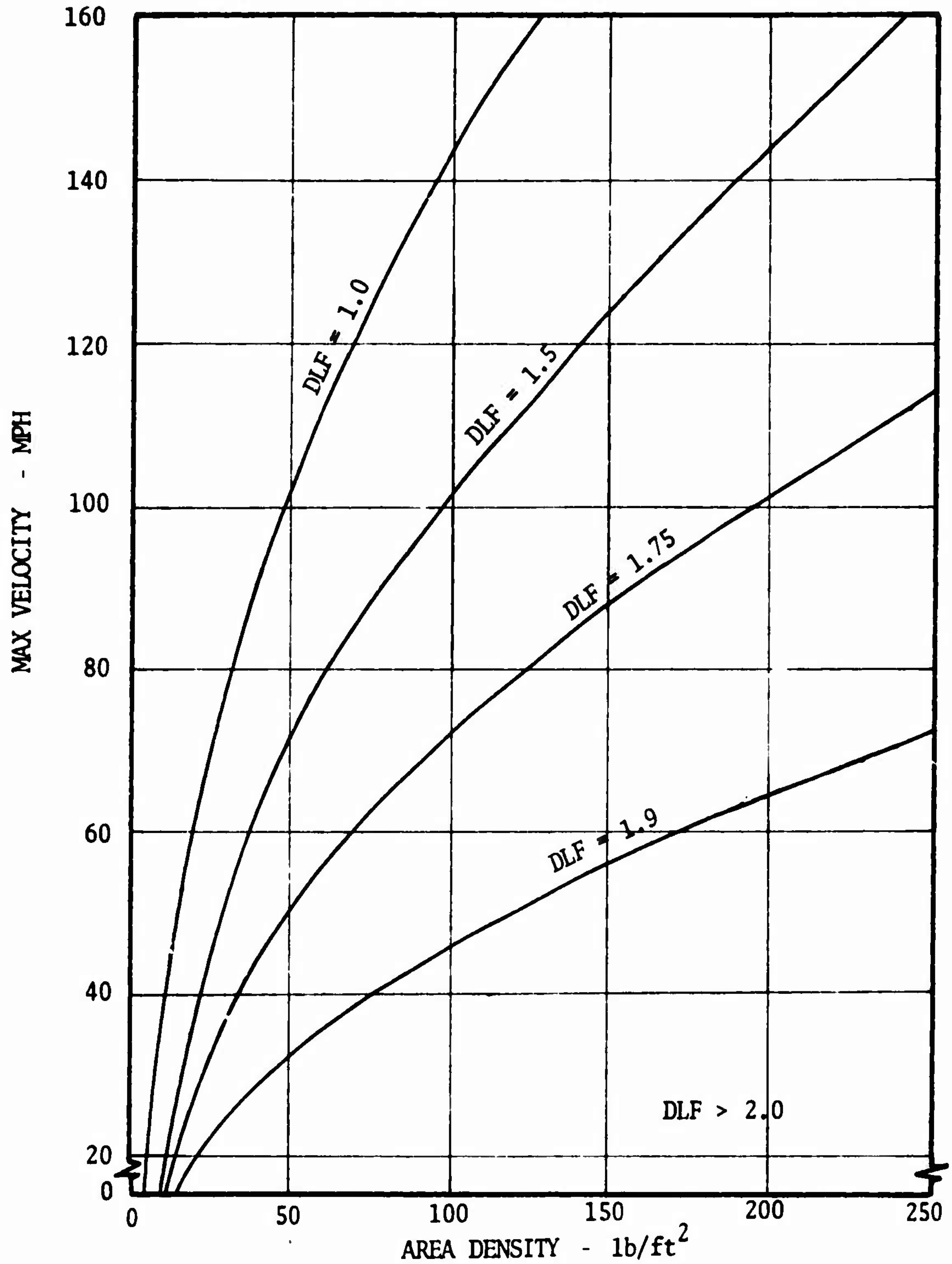


Figure 10. Allowable Flight Speed for Pallets With Varying Area Density and Load Factor.



Figurc 10. Continued.

It is seen that the permissible flight speed can be increased to a maximum by reducing the overturning moments produced by the variable forces of lift and drag. The drag moment can be reduced to zero if the pallet attachment points are raised (through the addition of stanchions at the four corners) to the height level of the center of the drag area. Then the moment equation becomes

$$M_W = M_L$$

$$50\, A\, \frac{A}{2} = .6\, a\, q\, \frac{A}{2}$$

$$50 = .6\, q$$

$$q = 83.333$$

$$83.333 = 1/2\, \rho\, V^2 = .00255V^2 \text{ (MPH at sea level)}$$

$$V_{max} = 180.78 \text{ MPH}$$

If the attachment points are raised again, then the pallet (which became a gondola with the addition of stanchions) will tend to rotate about the forward attachment points (instead of the rear attachment points) and the drag again contributes to the overturning moment; therefore, the permissible flight speed will be reduced accordingly.

VERTICAL BOUNCE

Vertical bounce was investigated to determine what effect, if any, the gondola structure might introduce. The vertical bounce phenomenon occurs when an outside force such as a slung load is introduced to the system (helicopter). If the slung load suspension system and the helicopter have a coupled frequency less than the helicopter natural frequency, significant aircraft vibrations will be experienced. The recommended procedures to determine this coupled frequency are presented in Reference 4. The parameter which can be selectively controlled in avoiding a nontrivial frequency is the spring constant of the sling system. The spring constant of the gondola is several orders of magnitude greater than any of the spring constants of the sling system. Therefore, the spring constant of the gondola should have no effect on the system coupled frequency.

MATERIALS AND METHOD OF CONSTRUCTION

The choice of materials and methods of construction must satisfy the following parameters, Structural Integrity

Environmental Resistance

Minimal Cost

Attendant factors weight, strength, availability, and cost must be inherent in the choice of material and the method(s) of construction.

Methods of Construction

Aside from the basic material properties are those characteristics which provide ease of fabrication (machinability, formability, and joinability). These factors influence both structural application and fabrication costs. Principally, the gondola requirements are light weight, ruggedness, and porous structure. The criterion for light weight suggests the use of a material that has a high strength-to-weight ratio and should be available in structural shapes which are efficient in reacting the principal load conditions. Since the pallet/gondola is acquired at load points which are at or above the load CG, the floor is subject to bending and shear loads which are in turn transferred to the lift attachment points. The relatively high load encountered locally requires significant shear and bearing properties of the materials. To satisfy the floor bending and shear loads, it is suggested that beam members or a monocoque structure of skin and stringers or honeycomb sandwich which may be joined by welding, brazing, adhesive bonding, or riveting be used. The transfer of local loads requires local reinforcements which distribute the load transfer over a fairly large area of the relatively weak skin of the monocoque structure. In addition, the monocoque structure is difficult to repair without special tools and in some instances facilities. The use of sheet stock for the monocoque structure makes it highly vulnerable to impact damage and related degrading effects from corrosion and abrasion. The loss of a few mils of material of thin-gauge sheet stock becomes a significant percentage of the working material. In summary, the damage threshold and the load transfer detract significantly from the weight saving that might be expected from monocoque structures. Additionally, the monocoque floor system requires significant reinforcement for axle bearing loads and local loads due to tie-downs.

Field experience from bonded sandwich structures utilized in pallet construction reveals a high vulnerability to compression failure in the sandwich core material and delaminations. It appears that the potential for this type of construction is low-cost retirement life-cycle applications. Since the gondola requires elevated lift points for stability, the support structure of these points must be integrated into the overall structure to support the bending moments due to floor loads. Structural efficiency would dictate that the side support structure be utilized as a truss. For convenience of fabrication and economy, the principal structural framing members can be comprised of axial load members. The side truss members can be pinned for field removability, affording access for loading or for stowing compactly. The floor system joining the principal side truss frame is composed of crossbeams which support a porous grating overlay. This floor when compared to a monocoque system demonstrates comparable weight savings with the added features of impact and corrosion resistance, cargo tie-down provisions, and field replaceability. The use of rugged structural shapes allows the designer the option to use mechanical fasteners or to weld the members without supplemental doublers or machined fittings. The material should have properties compatible with this method of joining, which requires good shear and bearing variability; these characteristics are not embodied by the anisotropic materials such as fiber reinforced plastic (FRP) and wood. These materials demonstrate good structural properties when utilized in composite monocoque structure or when compound curvature is a premium design consideration.

Structures which may be analogous to the gondola in their operational interfaces are containers and load-bearing pallets. Containers are constructed of various materials including the common steels, aluminum, fiber reinforced plastic, and wood. Pallets utilize approximately the same materials, with wood as the predominate material. The fact that containers are a complete enclosure, sheet-stringer or composite structures of wood and fiber reinforced plastic are frequently employed. The container structure, because of its closed feature, utilizes sheet stock in the sides, ends, and top. Experience has shown this feature to be highly susceptible to impact damage, corrosion, and cracking around fastener penetrations.

The desirability of rugged and porous gondola structures permits the designer to efficiently support the load by a trussed side and end structure that has relatively thick walled members. The containers generally utilize rugged structural shapes for floor side beams and transverse cross members. Although the container floor design capacity (lb/ft^2) is higher, it does not experience the dynamic load factors encountered in externally slung helicopter transport. Additionally, the roof and upper siderail members are inadequate for top corner lifting. Although some of the structural requirements are analogous to the container, the elevated lift points with attendant angular sling loads required a substantial increase in member sizing, particularly the upper siderail member and its secondary truss members.

Several significant material and construction disadvantages are apparenet from a review of container pallet designs which should be avoided. This evaluation suggests the use of rugged structural members of a material which has high strength-to-weight ratios, is corrosion resistant, and demonstrates good shear and bearing properties.

Materials

Selection of materials to construct pallets/gondolas presents a dilemma when one considers the myriad options which include composites and their fibers and orientation. Evaluation of candidate materials for this application will of necessity be limited to the following salient characteristics:

Strength-to-weight ratios to minimize tare weight.

Price-to-strength ratios to minimize cost.

Corrosion resistance to minimize in-service degradation.

Mechanical properties other than strength which would affect serviceability.

Availability of shapes and degrees of processing to achieve the end product.

There is no single figure of merit which can be assigned to each of the materials. However, several comparisons can be presented which reflect trends and limit the candidates to a degree.

Strength-to-Weight-Ratios

Since the pallet/gondola will be transported by helicopter and quite possibly by fixed-wing aircraft, it is imperative that the tare weight be kept at a minimum. The relatively high operating costs of these transportation modes must be utilized carrying cargo rather than tare weight. Several candidate materials used in the aerospace and commercial container industry are presented. Strength-to-weight ratios are presented in Figure 11. It is observed that two aluminum candidates rank the highest on the scale. Although some materials such as advanced composites and certain other metals would rank higher, they are not considered for obvious cost and utility. These two alloys are widely used in aerospace structures, but due to their susceptibility to corrosion, they are not used in the maritime industry. However, the next aluminum candidate ranks above average on this scale and possesses other desirable properties.[9]

Bidirectional fiber reinforced plastic materials demonstrate good potential behind the aluminum alloys. It would be possible to select a fiber reinforced plastic with a highly unidirectional characteristic to its reinforcing fabric and show fiber reinforced plastic to be superior to aluminum.[10] However, with a reasonable balanced fabric and resin matrix, fiber reinforced plastic ranks more favorably than aluminum alloy 6061-T6. Figure 11 shows, however, that even a bidirectional fabric such as 181, which loses approximately 10% of its strength in the transverse direction, loses approximately 50% of its strength in the 45° direction. In general, the fiber reinforced plastic when used in sandwich structures compares favorably with aluminum. The advantages of fiber reinforced plastic are best exploited when load paths are predictable to take advantage of the directional properties of the material. However, the relatively low bearing and shear strength of fiber reinforced plastic imposes restraints that isotropic materials do not.

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[9] Military Handbook Strength of Metal Aircraft Elements, Department of Defense, MIL-HDBK-5, 1 September 1971

[10] Military Handbook Plastics for Aerospace Vehicles, Department of Defense, MIL-HDBK-17A, January 1971

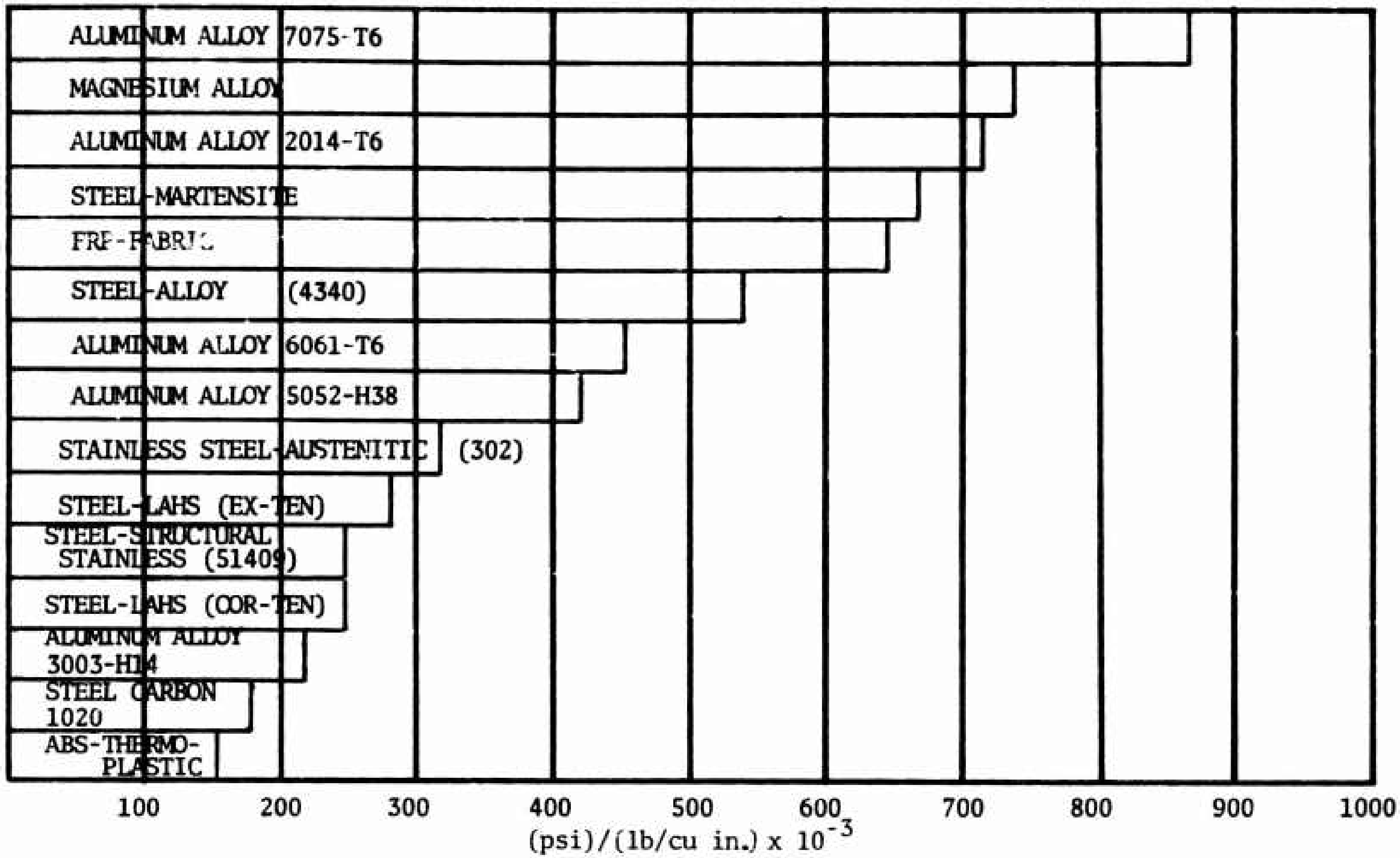


Figure 11. Strength-to-Weight Ratio.

Steels range widely on this scale from the high ranking of martensitic steels to the low ranking of the carbon steels. The corrosion-resistant steels do not demonstrate an advantage over corrosion-resistant aluminum.

Strength-to-weight difference, while not a conclusive indicator for selection of material, does provide an indicator to the designer. However, this factor alone would be misleading when one selects a high-ranking steel which allows thin sections but which would be severely degraded by corrosion and vulnerable to impact. On the other hand, a low-ranking material when used in composite construction becomes efficient.

Cost/Strength Ratio

The consideration of a cost parameter in material performance comparisons is essential, since the application of engineering materials invariably includes economy as a decision factor.

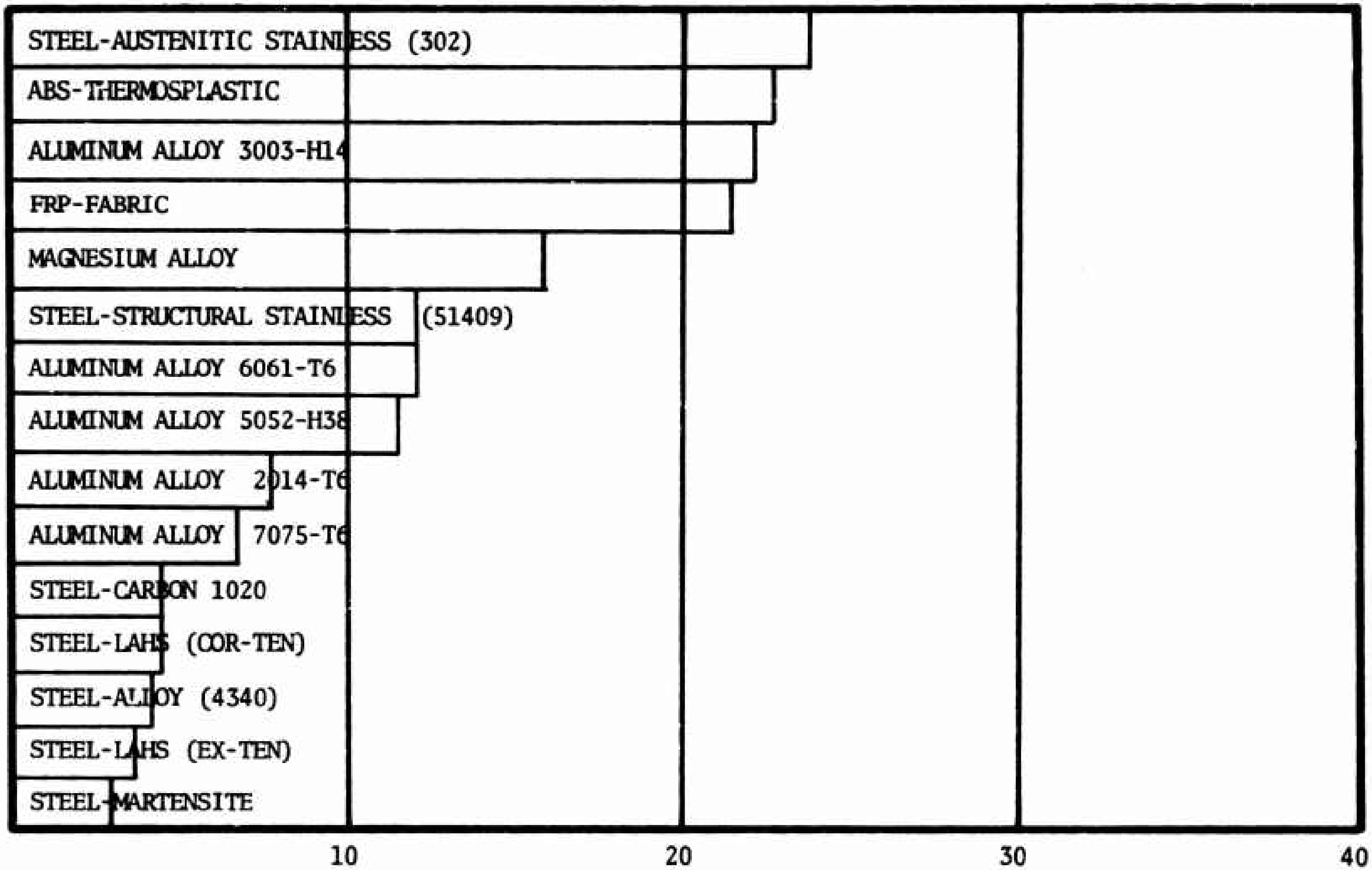
The advantage of steel is immediately obvious. Most of the low-ranking (favorable) positions are occupied by steel. The higher strength steels are in the most favorable positions, showing that, in general, costs do not rise in proportion to the gain in strength. It is also apparent that no cost penalty must be paid for the improved corrosion resistance of COR-TEN. However, the fully stainless group of steels is not in this favorable position. (See Figure 12.)

Aluminum alloys are in the mid-range positions. There is a sharp increase from steels to aluminums. Then the aluminum alloys increase from the stronger alloys upward, similar to the behavior noted for the steels. Thus, economy considerations would lead to selection of the higher strength alloys. This is particularly true when the corrosion-resistant steels are compared to aluminum 6061-T6.

It should be noted that aluminum showed a more favorable position in Figure 11 than its ranking in Figure 12. Similarly, fiber reinforced plastic shows a similar reversal. It appears that the higher strength alloys of steel and aluminum show a favorable trend in cost-to-strength comparisons.

Composite Rating

Composite rating of the materials is difficult; however, the alloys of aluminum and steel demonstrate the most favorable position overall. The most frequently used alloys of aluminum in structural applications (5052-H38 for sheet and 6061-T6 for extrusions) are medium in their ranking with respect to the other alloys. Their corrosion resistance rating is excellent in industrial atmospheres and good to very good in marine atmospheres. Their availability in both sheet and structural shapes permits flexibility for the designer.



$\left(\frac{\text{Cost/lb x Density}}{\text{Ultimate Tensile Strength}}\right) \left(\frac{\text{c/cu in}}{\text{psi}}\right)$ 100,000).

Figure 12. Cost/Strength Ratio.

Aluminum alloy 7075-T6 demonstrates an overall advantage over the more common 5052 and 6061 alloys. However, its poor weldability and less resistance to corrosion detract from its composite rating. This alloy, with proper surface treatment, should be used whenever welding can be avoided. Although aluminum rates lower overall than the alloy steel, its superior corrosion resistance gives it a decided overall advantage.

Fiber reinforced plastic material compares less favorably overall than do all the alloys of steel and aluminum unless directionality of load is controlled. The advantage of fiber reinforced plastic tends to improve in composite sandwich structures when used as a face sheet. However, the desirability of rugged and porous structures tends to minimize a favorable application for this material for gondola fabrication.

The composite rating of alloy steels would suggest that they be considered to the maximum extent. However, to take advantage of their composite rating would in many instances dictate relatively thin wall shapes, which are prone to impact damage, and high percentage thickness reduction due to corrosion and abrasion. These factors point out the pitfalls using rating indices.

A composite rating of materials based solely on strength, weight, and cost is, at best, an indication only. The final choice must be resolved for the application. The application of these materials in an efficient load-carrying pallet/gondola structure can be further analyzed by the material shape availability and resistance to environmental degradation. The basic design constraints previously mentioned which are pertinent to the structure are as follows:

Cube Capacity

Payload Capacity

Minimum Tare Weight

Elevated Lift Points

Porous Structure

Corrosion Resistance

Impact Resistance

Fatigue

The first two requirements have little or no impact on the choice of materials. However, the remaining characteristics are significant to material selection.

Minimum tare weight is a function of strength-to-weight ratio and available shape for optimized placement. Certain materials may demonstrate favorable strength, weight, and cost, but they are not available in an efficient shape. Structural requirements of porosity and ruggedness to minimize impact damage suggest the avoidance of thin gauge sections. Therefore, the use of structural members will be paramount and the material should be easily formed or extruded. Additionally, the material must demonstrate good joining capability. This becomes an immediate problem with plastics and fiber reinforced plastic, which must be reinforced locally to distribute the load transfer over a relatively large area.

Therefore, the material should be readily joined by mechanical fastening, welding, brazing, etc., which are relatively inexpensive methods compared to adhesive bonding at local connections. Additionally, the material must demonstrate good bearing and shear strengths consistent with efficient joints. Fatigue strength of the candidate materials is nearly proportional to ultimate strength and will invariably follow the ranking of strength-to-weight ratios. From this material evaluation, the two candidates which offer the greatest potential are aluminum and steel. Therefore, judicious use of these materials should be considered for the framing members as a minimum. Joints and connections to minimize bulk may of necessity utilize steel and continuous members utilize aluminum.

SUPPORT EQUIPMENT

Support equipment for the gondola, in addition to the interface requirement with the helicopter and other transportation modes, will include, to the maximum extent, available materials and equipment organic to the transportation terminal. The gondola by its nature provides bearing containment of the load with its floor system; however, end, side, and top containment must be supplemented in these areas by straps, nets, and dunnage fabricated in place. Available equipment and materials appear to be adequate to support the utilization of the pallet and gondola. The salient interfaces of the support equipment are as follows:

Loading

Restraining

Ground Mobility

Attachment to Helicopter

Unloading

Return

Any one, or all, of these interfaces may require some support equipment which could be identified during logistic supply trials. However, the equipment which appears to be inadequate is ground mobility support at both the terminal and user organization.

LOADING

The gondola can be loaded by using conventional materials handling equipment such as conveyors, hand trucks, ramps, and forklifts. The standard MHE could be used to load and unload break-bulk cargo.

A desirable feature of the gondola would be one which permits the load to be placed from the side or ends. Invariably, all the concepts considered may be loaded from the top and both ends by removing two diagonal braces. In most cases one or both sides can be removed by simply unpinning. Where it is desired to allow a forklift to traverse the floor of the gondola, dunnage material such as plywood or planking could bridge the grated floor. Floor structure sufficient to allow a 4,000-lb forklift carrying a 2,000-lb load adds 500 lb or more to the base structure. Accessibility in placing loads on the gondola by forklift is advantageous since the gondola, unlike a container, permits loads which can extend above the top plane. A typical listing of MHE equipment from Reference 11 is shown in Table 7.

[11] FM101-10-1, STAFF OFFICERS FIELD MANUAL, July 1971.

TABLE 7

MATERIAL-HANDLING VEHICLES [11]

ITEM	LOAD (LB)
Truck, forklift	
X49188	2,000
X50284	4,000
X50421	4,000
X50969	6,000
X51106	2,000
X51243	2,000
X51380	4,000
X51654	4,000
X51791	6,000
X52202	6,000
X52339	6,000
X52613	10,000
X52750	15,000
Truck, forklift, rough terrain	
X51928	6,000
X52476*	10,000
Truck, platform, util, 1/2T, 4x4, with equipment	
X55627	10,000
Crane, truck, whs	
F38967	6,000
F39104	10,000
Truck, straddle-carry	
X56997	30,000

CARGO RESTRAINTS

Cargo can be secured by using conventional methods such as straps, cables, and chains. Table 8 lists the available federal stock numbers of materials for securing external cargo. In addition, a listing of aircraft tie-down materials is included in Table 9. Some of the concepts have tie-down rings located in the base of the gondola similar to aircraft internal cargo provisions. In addition, the floor system is porous, permitting the riggers to pass straps, wire, rope, etc., in securing the load to the crossbeams or other base structure. Since the gondola as conceived is an open trussed structure, some supplemental containment of small items may be desirable to minimize tie-down straps. It appears that some of the available nets could be utilized in this manner. Additionally, dunnage material could be fitted to the sides and ends to facilitate the containment of loose items. In general, the gondola affords flexibility in cargo tie-down and restraint.

GROUND MOBILITY

Ground mobility of the gondola should be provided in forklift, mobilizer dollies or skids. The most direct and efficient method is by forklift. However, the available forklift capacity organic to the terminal transfer unit does not have sufficient capacity for the 20,000-lb capacity gondola. Unless the loading and unloading of the gondola is accomplished at the acquisition site, the loaded gondola could not be moved with existing forklifts. Since the gondola is designed for transport by vertical lift, it is desirable to use the lift points for surface transport as well. This would require a straddle carrier or a mobile crane unit. However, provisions for forklift handling should be required. Additionally, those pallet/gondola concepts having an 8-x-8-ft cross section can be transported by highway or rail. Some of the gondola concepts presented do not directly permit forklift handling; however, they would accept top-lift carriers or straddling transporters. This type of equipment is presently not available and would introduce new requirements.

HELICOPTER ATTACHMENT

Helicopter attachment is accomplished through a load acquisition device or a sling set having one or more legs. The gondola must provide a suitable attachment point to which slings may be secured. The attachment point to the load shall always be at or above the mid-height of the load. All of the gondola configurations present either single-, two-, or four-point load attachment, which permits attachment to either of the helicopters.

Single Point

The CH-47 helicopter has single-point attachment, while the CH-54 has both single- and four-point attachment. The CH-54 is assumed to use single-point attachment since the limited length of the individual four-point reels do not lend themselves to efficient rigging and load acquisition in

TABLE 8
EXTERNAL CARGO-HANDLING MATERIALS*

FSN	NOMENCLATURE	RATED STRENGTH (LB)
1670-090-5354	Clevis, Suspension, Large	40,000
1670-242-9169	Bag, Cargo, A/C A-22	2,200
1670-242-9173	Bag, Cargo, A/D A-21	500
1670-251-1153	Sling, Cargo, A/D A-7A	15,000
1670-360-0300	Clevis, Cargo Platform	15,000
1670-360-0304	Clevis, Suspension, Small	20,000
1670-360-0308	Clevis, Suspension, Medium	20,000
1670-360-0466	Ring, D, Prcht Harness (MIL-H-7195)	5,000
1670-360-0540	Strap, Tiedown, A/D, 15ft	5,000
1670-753-3788	Sling, Cargo, A/D, 3ft, 3 loop	20,000
1670-753-3789	Sling, Cargo, A/D, 8ft, 2 loop	13,500
1670-753-3790	Sling, Cargo, A/D, 9ft, 2 loop	13,500
1670-753-3791	Sling, Cargo, A/D, 11ft, 2 loop	13,500
1670-735-3792	Sling, Cargo, A/D, 12ft, 2 loop	13,500
1670-753-3793	Sling, Cargo, A/D, 16ft, 2 loop	13,500
3940-641-3409	Sling, Cargo Net, Nylon Rope 8 x 8	unk
3940-641-3410	Sling, Cargo Net, Nylon Rope 10 x 10	unk
3940-856-7998	Sling Set, Cargo, Universal	7,500
3940-675-5001	Sling, Endless, 10" dia.	7,500
3940-675-5002	Sling, Endless, 4' long	2,500
3940-675-5003	Sling, Endless, 8' long	2,500
3940-744-8507	Sling, Cargo Net, Steel Wire Rope	5,000
3940-392-4375	Sling, Cargo Net, Nylon 12 x 12	unk
1670-823-5040	Sling, Cargo, A/D 11ft, 3 loop	20,000
1670-823-5041	Sling, Cargo, A/D 12ft, 3 loop	20,000
1670-823-5042	Sling Cargo, A/D 16ft, 3 loop	20,000
1670-823-5043	Sling, Cargo, A/D 20ft, 3 loop	20,000
1670-902-3080	Sling, Cargo, Multiple Leg (Chain Leg)	40,000
1670-902-3080	Sling, Cargo, Multi-leg	15,000
1670-242-9169	Bag, Cargo, Aerial Delivery, Type A-22	4,000
3990-926-1047	Pallet, materials handling, double-faced, nonreversible, slotted, wood, 4-way entry for forklift	unk

*[12] TM 55-450-8, Air Transport of Supplies and Equipment, External Transport Procedures, December 1968

[13] TM 55-450-11, Air Transport of Supplies and Equipment Helicopter External Loads, Rigged with Air Delivery Equipment, June 1968

[14] TM 55-450-12, Air Transport of Supplies and Equipment Helicopter External Loads for Slinge, Nylon Chain, Multiple Leg (15,000 lb cap) Jun 1969

[15] TM 55-450-19, Air Transport of Supplies and Equipment Helicopter External Lift Rigging Materials Techniques and Procedures

TABLE 9
INTERNAL CARGO RESTRAINT MATERIALS

NOMENCLATURE	GOVERNMENT PART NO.	CAPACITY	SPECIFICATION	REMARKS
Strap	AF Type A-1A	1,250 lb	MIL-T-7181	Strap 15' to 9'
Strap	AF Type MC-1	5,000 lb	MIL-T-8652	Strap 20' to 12"
Cable	AF Type, B-1A	500 lb	MIL-T-6272	Cable 15' to 23"
Chain Assy	AF Type, MB-1	14,000 lb	MIL-T-25960	Chain 9' to 10.9 lb
Chain Assy	AF Type, MB-2	35,250 lb	MIL-T-25959	Chain 9' to 25.25
Net Cable	A2	-	MIL-T-8166A	15 x 15 cable net 36.5 lb
Net Nylon	MA-2	5,000 lb	MIL-T-26780	Nylon web net 15' x 15'

hover. The single-point suspension presents problems of in-flight stability which limits flight speeds well below normal. The principal cause of this instability is the flying of bluff bodies broadside to the airstream. Two deleterious effects are encountered from this lack of yaw control: the drag forces reduce speed and the trail angle becomes sufficiently large to jeopardize safety of flight. Since it is not practical to shape the load to the desired aerodynamic profile, the problem remains. Various methods have been tried, but all appear to be less than desirable for operational suitability. These methods were attachment of drogue chutes or vertical stabilizers. The drogue chute which trails the load may become entangled with the aircraft and present a safety-of-flight hazard. The vertical stabilizers require an area which is approximately one-third to one-half the projected drag area of a slung load. This surface becomes a fairly bulky appurtenance which interferes with economical ground handling and storage, and adds tare weight. A similar effect can be achieved by loading the gondola such that the CG is at or near the forward one-third of the longitudinal span, with the sling apex above the CG. This will cause the load to fly with the least drag area.

All of these methods are poor solutions. Since this problem is encountered for each cargo sortie, its solution might better consider either a modification to the helicopter or an attachment to the helicopter which provides this yaw stability. A comparative analysis of drag load caused by the yawing of the load to fly broadside is presented in the section on Stability.

Four Point

Four-point attachment capability is encountered on the CH-54 helicopter only. These points have limited adjustable lengths of 12 and 16 ft, dependent on the model. The capacity is 5,000 and 8,300 lb respectively. This configuration will require that the aircraft acquire the load by straddling or by attaching a sling leg to each of the reels. However, the four-point attachment, which would provide maximum in-flight suspended load restraint when rigged to four load points, is capacity limited and not a normal configuration mode for the CH-54.

Two Point

The two-point attachment is planned for the HLH aircraft. The two points may be separated by 13 to 16 ft and will have hoisting capability. Combined load capability is 70,000 lb. The two-hoist system provides sufficient stability to fly external loads at or near normal cruise speeds. Loads are restricted in yaw, with attendant pitch and roll restraint. However, the significant improvement is achieved by restricting yaw. This permits the designer to configure the gondola to present the least drag area to the direction of flight. Two or four load suspension points can be used. Two load points could be engaged by the cargo hook, while the four-point system would require a two-legged sling at either end.

LOGISTICAL AND TECHNICAL MISSION REQUIREMENTS

The logistical and technical mission requirements of the gondola are to provide delivery of cargo by helicopter as an externally slung load. The cargo to be transported will consist of vehicles and equipment which are noncontainerizable. Additionally, the gondola can be utilized for transporting break-bulk cargo in forward areas. Its porous and stowing density when empty allows for efficient low-cost return with minimal drag. In addition, the gondola should have the capability to clear cargo from air and surface terminals in support of the "through-put supply" concept. The helicopters which will be the transport vehicle may be classified as medium- and heavy-lift aircraft. Therefore, the loading capacities of the helicopters will affect the size of the gondola utilized in the through-put supply system. The continuous gondola will accommodate the capacity of either the 25,000-or 30,000-lb capacity of the CH-47 and CH-54, and a larger gondola will accept the 60,000-lb capacity of the HLH.

Interconnection of the larger gondolas would permit the transport of outsized loads or multiplicity of single items such as vehicles and equipment (see Table 2). This versatility could also allow transporting supplies that would be disbursed at two or more user organizations. Particular attention must be given to the connection, which invariably must transfer relatively high loads, and the connection shall be simple with minimal mechanical lash and no special tools.

HELICOPTER MISSION

To focus on the gondola in the external cargo transport by helicopter, a typical supply mission is examined. Analyzing a typical mission of 25NM, the helicopter can fly two missions per hour. For the CH-47 this would result in the delivery of two 10-ton loads of cargo. The Terminal Transfer Company work unit, comprised of five men could stuff, secure, and rig a gondola in approximately three hours. The off-loading should be accomplished in approximately 1.5 hours. During this time frame, the helicopter would deliver nine gondolas. From this example it would appear that for each CH-47 helicopter, the system should provide approximately nine gondolas. As the mission radius increases, the number decreases to a point that when the helicopter is flying at maximum range, approximately three gondolas are required. Applying similar logic for the CH-54B and HLH with higher capacity (especially the HLH) would require proportionally more gondolas per helicopter. However, the number could be reduced if loading and unloading time is improved by providing improved mechanical assistance. Roll on/roll off capability is readily achieved by using shallow ramps or by using dunnage to bridge the seven-inch floor height.

To accomplish any segment of the supply mission where the gondola is used, no technical advancement is introduced that is not already available at the normal cargo handling units. A typical combat logistics scenario is

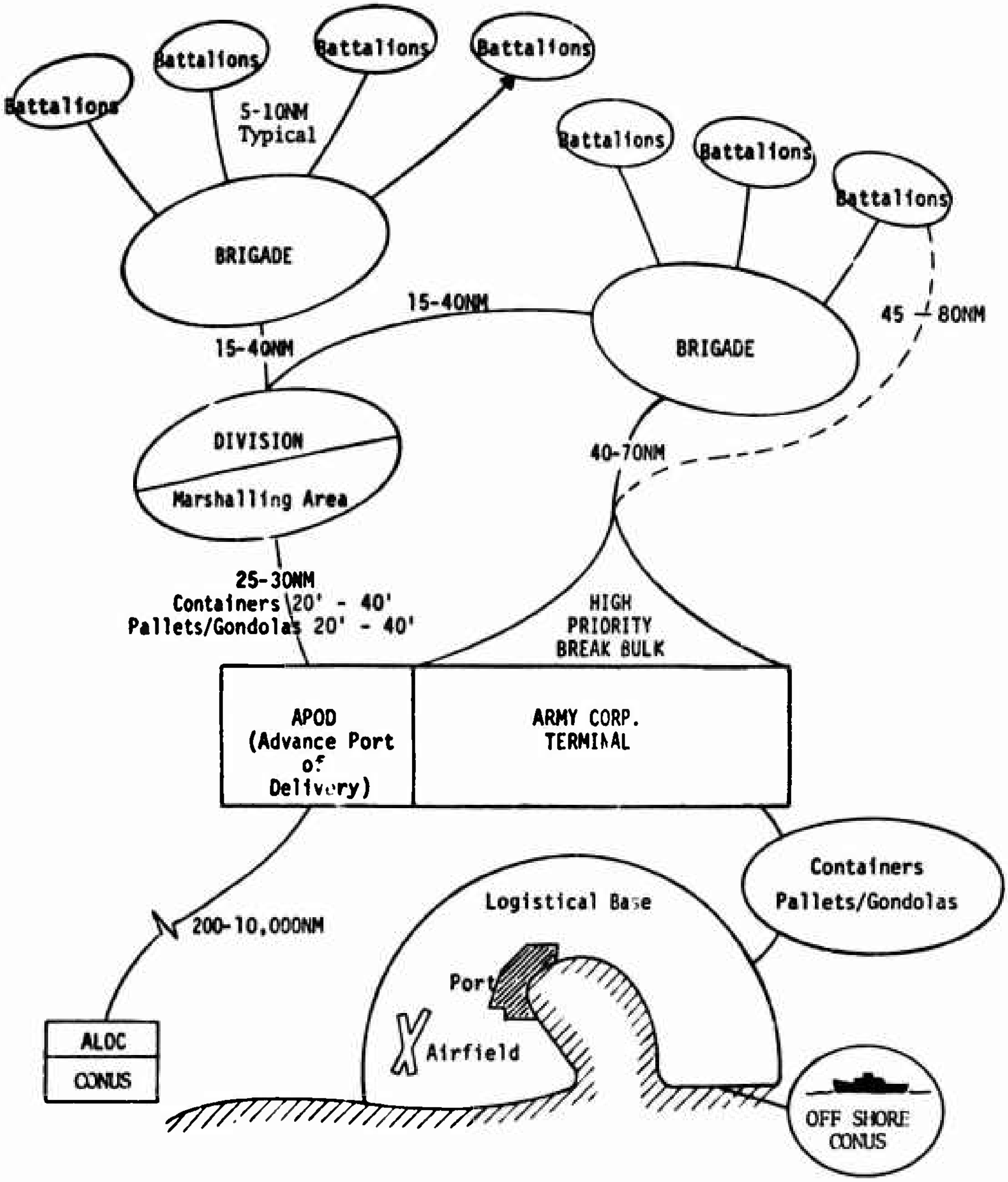


Figure 13. Typical Logistics Interfaces for Gondola Utilization.

depicted in Figure 13. The role of the gondola is further extended in its use as a shuttle vehicle in transporting combat vehicles over interrupted surface routes such as craters or unserviceable bridges. Additionally, the gondola use in ship-to-shore off-loading is a key function when off-loading vehicles and equipment in particular multiple unit loads. Personnel familiar with rigging other external cargo for helicopter transport should minimize errors of judgement, since fixed load points are available. However, weight and balance provisions should be made available to limit center-of-gravity unbalance. This could be accomplished at the transfer terminal but would require care in judicious placement of cargo in the forward areas. Tie-down provision for break-bulk cargo and equipment will be integral to the pallet base. Attachment to the aircraft will be made by slings and pendants which have the capacity to support the potential payload.

In Flight

Operation of the helicopter should be typical for external cargo operations. Experience should be demonstrated prior to flying tactical supply missions.

Returns

Return of the empty gondola can be accomplished in multiples since most of the concepts will stow at one-fourth the cube of the deployed mode. The goal of the design should allow the return of four empty gondolas in the volume occupied by one fully loaded gondola.

Terminal Requirements

The gondola terminal handling requirements are similar to those experienced for containers. The open frame upperstructure permits ease in roll-on/roll-off loading and unloading. This is accomplished with standard shallow ramps or by bridging with available dunnage material. The volumetric size and payload are nearly identical to that experienced for containers. The loading and unloading can be accomplished by similar means. However, more flexibility is permitted by the gondola since the top is open and since the ends and, in some concepts, the sides are removable. The use of hand trucks and small forklifts for loading and unloading can be used when available. This equipment is standard TOE for a terminal transfer unit. However, the movement of a fully loaded gondola within the terminal cannot be accomplished with existing forklift capacity. Therefore, terminal transfer units must be equipped with mobile lifting equipment with 25,000- and 60,000-lb capacity. The mobile lifting equipment need not be forklift devices but could be gantry or straddle carriers, which engage the gondola at the lift points used by the helicopter.

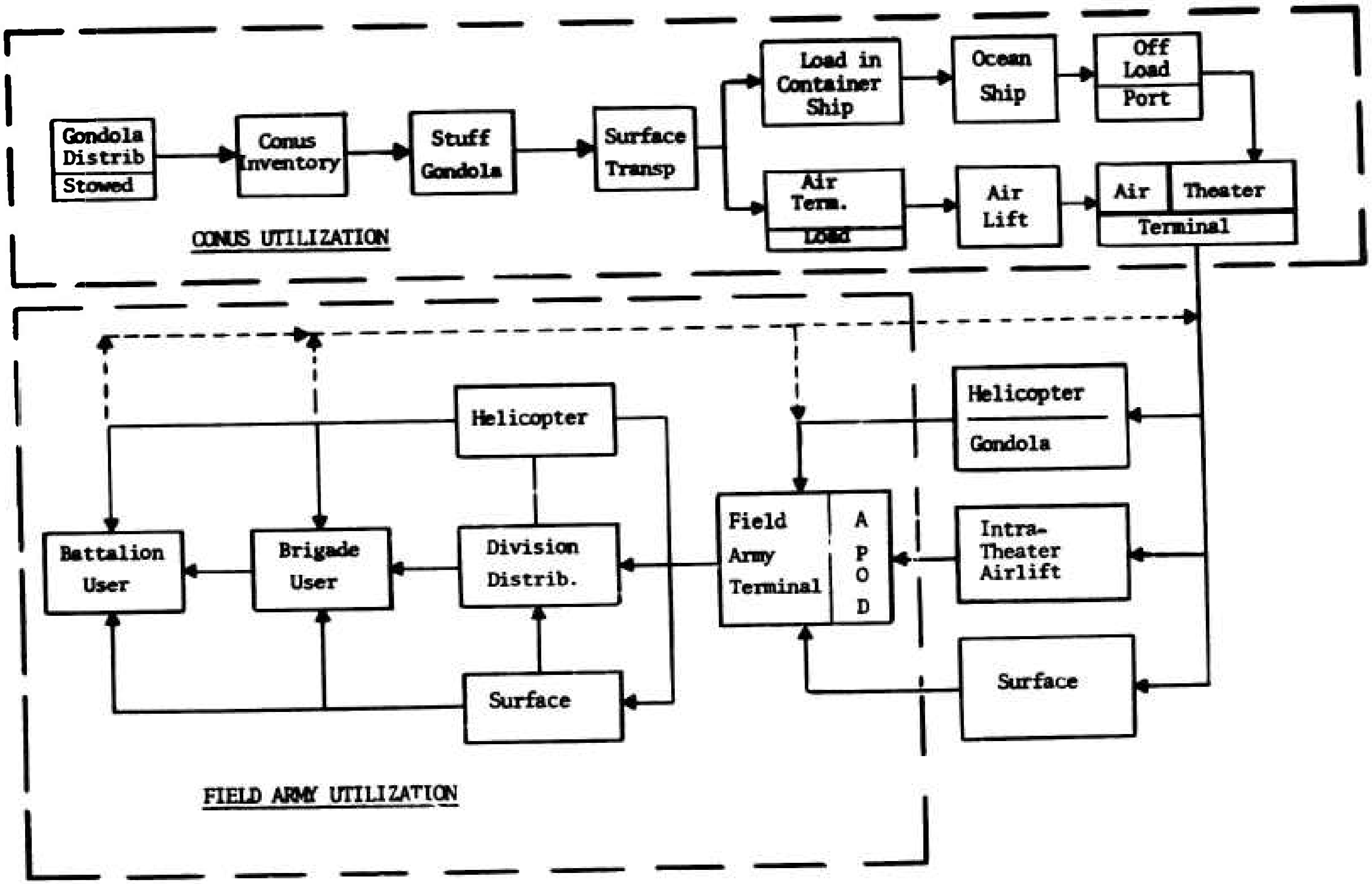


Figure 14. Gondola Utilization Flow Diagram.

Intermodal Requirements

The flow diagram presented in Figure 14 demonstrates that the gondola should also have intermodal capability, to eliminate transhipment of the cargo. The external geometry of the gondola should comply with the requirements of air, sea, and surface modes of transportation. As previously discussed, the required volume to satisfy the payload capacity of the CH-47 and CH-54 is approximately 1,000 cu ft, which is achieved with an 8-x-8-x-20-ft gondola. This size gondola is compatible with all modes of transportation. However, to meet the 463L system requirements, the base must be smooth for conveyor loading. Since this is only one segment in the through-put supply system, the gondola could be carried by three 463L, Type I pallets used in the slave mode. Thus, the gondola could satisfy all principal modes of transportation. Principally the gondola should be compatible with surface modes of transportation, and in contingencies it could be utilized in fixed-wing transportation. It is appropriate to identify some of the interface features which are desirable:

AIR--The base structure must provide a smooth continuous surface for conveyor loading and the 463L cargo system or equivalent for aircraft internal cargo.

RAIL--Base structure corner fittings to meet ANSI/ISO container requirements.

TRUCK--Similar to rail requirement.

OCEAN--Shall conform to modular sizing based on the standard 96-x-96-in. end profile plan size. Stacking up to six tiers shall be permitted.

These modes, in addition to the helicopter external cargo mode, impose constraints of length, width, height, and weight. Also, the dynamic loading of the various modes can impose additional structural requirements or compromise of the helicopter loading criteria. Dynamic load factors and internal cargo capacities for other transportation modes are given in Tables 10 and 11.

Modular sizing of pallets and gondolas is desirable from several vantage points:

1. It would serve the load capacity of all three helicopters: 20,000 to 25,000 lb and 60,000 lb. However, the external size of the gondola would not violate the 8-ft width or the 8-1/2-ft height of ocean shipments.

TABLE 10
INTERMODAL CARGO VOLUMES

SHIPPING MODE	CARGO SPACE DIMENSIONS			
Fixed Wing	Length (in)	Width (in)	Height (in)	Weight (lb)
C-130	470	109.0	106	25,000
C-141	810	123.0	106	55,000
C-124*	898	124.0	133	24,000
C-133*	976	144.0	141	60,000
C-5A	1,452	228.0	114	180,000
HELOS				
CH-47	366	7.5 90	78	20,000
CH-54 (POD)	326	106	78	20,000
HLH	--	--	--	60,000 (external)
SEA	240	96	96	44,800
	288	96	96	50,000
	420	96	96	61,600
	480	96	96	67,200
RAIL (Flat)	519 to 648	126	132	100,000 to 200,000
TRUCK	480	96	96	40,000

* No longer in service.

TABLE 11
INTERMODAL DYNAMIC LOAD FACTORS **

Direction of Load Relative to the Axis of Container	Terminal Operations	MARINE	HIGHWAY	RAIL	AIR FIXED WING
Downward	2.0	1.8	1.7	1.5	3.0
Upward	0.0	0.0	0.0	0.0	1.11
Lateral	0.2	0.6	0.1	0.3	1.5
Longitudinal	0.7	0.6	0.7	1.8	3.0*

**Per AN STD. MH 5.1 1970

* 3g Per MIL-A-8421C when not loaded at same level as crew

2. Modular to Air, Ocean, Rail, and Highway

Interface dimensional requirements can be achieved with an 8-ft wide load, which is standard for both highway and ocean shipment. Current aircraft would accept slightly wider loads, or twice this width in the case of the C5-A. Modular lengths with respect to aircraft cargo length would accept 10-ft multiples. The 10-ft length module would utilize more than 75% of the allowable cargo length of the five principal fixed-wing aircraft presently available. Invariably, fixed-wing cargo aircraft are weight limited; therefore, the nominal load density of less than 20 lb/ft^3 would fully utilize the fixed-wing capacity. In the C5-A, as an example, could be stowed six 8-x-8-x-40-ft pallet/gondola loads equaling 15,360 ft^3, assuming that a normal payload of 180,000 lb yields a density of 11.75 lb/ft^3. This load density is approximately one-half the average cargo density of 20 to 25 lb/ft^3.

Intermodal requirements of the gondola can be achieved by restricting the width to 8 ft and the height to 8-1/2 ft or less. This restraint in no way compromises the gondola in its mission of transporting break-bulk cargo as a slung load on the helicopters. An interior clearance width of 9 ft would be more compatible with larger vehicles.

OPERATION SUITABILITY

Operational suitability of the gondolas must be demonstrated by the following criteria:

1. Sufficient capacity
2. Structure to support maximum payload with attendant load factor
3. Reliability
4. Maintainability
5. Transportable by one or more other modes
6. Environmental

The gondola concept selected as the preferred design meets the operational goals presented. Its primary operation will consist of transporting noncontainerizable cargo to include vehicles and equipment.

UTILIZATION

The gondola will normally be utilized in resupply operations with its principal applications predicated on the helicopter. This is not to preclude intermodal operation nor the fact that the HLH may be used in direct supply to forward area user organizations. However, there appears to be more efficient use of each size gondola and helicopters at particular segments of the resupply system. The continuous 20- and 40-ft gondolas accept nearly all vehicles and equipment organic to a road combat unit. The gondola design preserves the intermodal capability while satisfying the helicopter external cargo requirements. Therefore, the gondola could be employed directly at the port terminal when transhipment of high-priority cargo is required, or it could interface at any of the surface transportation terminal points. It appears that the gondola has all the capability of a container except protection of contents from weathering while providing sling load capability and safety and efficiency of empty return flight. The tare weight of the gondola is considerably less than that of containers of comparable size. The selected gondola design concept can interface with all modes of transportation within the existing system.

Operational suitability of the three helicopters utilizing gondolas is summarized in Table 12. Utilization of the helicopters is predicated on mission radius suitability, payload, and exposure risk from enemy engagement.

TABLE 12
OPERATIONAL SUITABILITY
HELICOPTER GONDOLA UTILIZATION

Mission Radius N. M.	Mission Description	HELICOPTER GONDOLA UTILIZATION		
		CH-47	CH-54	HLH
Less than 20	Division to Battalion	Common	Occasional	Rarely
20-60	Division to Brigade	Usual	Common	Contingency
60 or more	Field Army/ Terminal to Division	Common	Usual	Occasional
100 or more	Port/Terminal to Field Army/ Terminal	Occasional	Common	Common
5-10	Off-Shore to Terminal	Occasional	Occasional	Usual

Any one of the three helicopters could operate suitably throughout the resupply network from offshore unloading to and including forward area user organizations at the battalion level. However, it is quite obvious that the risk of losing the helicopter to enemy fire increases as the vehicle operates near the area or line of engagement. Therefore, it may be undesirable to expose the HLH (a high-value vehicle) to a high-risk mission of resupplying forward areas. While it may well be utilized for this activity, the problem of distributing the 25-30 tons of supplies after disengaging the gondola may be inefficient. Therefore, it may be appropriate to resupply with a smaller, more maneuverable helicopter such as the CH-47. The smaller payload of break-bulk cargo of the CH-47 becomes a problem for distribution in forward areas also, since full utilization of this ship delivers approximately 20,000 lb. It may be desirable to employ two or three smaller gondolas, any one or all of which could be distributed at or near each user during the same mission. These local resupply gondolas would be sized and rigged as far forward as division or brigade distribution areas. Loads would include break-bulk resupply items consisting of POL, ammunition, and rations. The full-size continuous gondola will offer higher payload utilization which will require breakdown distribution by surface mode to the user organizations. It appears that it would be more desirable to service small fire base units by introducing gondolas of a size smaller than those required for maximum payload of the helicopter.

Minimum exposure of the helicopter would suggest simply unhooking in hover and returning for another load. The empty gondolas could be recovered when the area becomes more or fully secured. Therefore, the return leg of the mission could be flown at V_{max}, with every third or fourth return leg designated as an empty gondola return. If the HLH was employed in forward areas, resupply distribution flexibility is decreased while risk value increases.

Gondolas used in rear areas (brigade and above) need not have the clustered/breakdown for local distribution but could be compatible with all transportation modes if the 9G fixed-wing requirement were waived. This requirement imposes a severe penalty on the design, particularly tare weight. The pallet can be sized for width compatibility to the ANSI/ISO standard size of 8-x-20-ft or 8-x-40-ft plan areas while accepting loads to a height of 8 ft and 8.5 ft respectively. This sizing would be compatible with highway, rail, and maritime transportability. If crash survivability of the 9G load by fixed-wing aircraft is not a requirement, the same size pallet/gondola could be utilized in the ALOC system. This size pallet/gondola would also be compatible with the container ship cell dimensions. Stackability for ocean shipment does not appear to induce excessive tare weight in the structure. However, the intermodal design shall not significantly compromise the basic objective of the resupply mission of the helicopter. Sizing methodology for helicopters and other modes of transportation appears in the section on Gondola Performance. Additional suitability requirements shall consider forklift openings for terminal handling and ground relocations, and smooth treadways for conveyor handling and locking devices to American National Standard Institute/International Standard Organization (ANSI/ISO) requirements.

RELIABILITY-MAINTAINABILITY

Reliability and maintainability requirements will be in accordance with AR 705-50. The goal of the design concepts is to provide a gondola that avoids the use of thin-gauge materials, with maximum utilization of rugged structural members having relatively high resistance to abuse and environmental degradation.

Reliability and maintainability of the gondola are predictable from the performance criteria established for the design, except for fatigue environment. A close approximation of the gondola service life can be predicted once the fatigue loads are measured. However, an assessment of the operational environment suggests that the gondola be constructed of heavy-gauge material such as extrusions, forging and castings to minimize the percentage loss of thickness due to abrasion, corrosion, etc., that would significantly compromise total structure integrity. Where such materials and/or thickness do occur, they shall be easily repaired or replaced with minimum complexity. Therefore, the types of structures conceived should demonstrate these attributes.

The reliability goal of the gondola system is to demonstrate a 95% probability of completing the helicopter mission. As shown in the section on mission requirements, the gondola could be utilized for several segments of the supply system. However, the forward resupply mission appears as critical as any of the other missions which interface at some time during the delivery cycle with the helicopter. Assuming 24-hour utilization at 2/3 yearly availability suggests that the gondola be used for 5,840 hours. A typical forward resupply mission would consume approximately 7 hours:

Load Rig and Attach	3 hours
Flight Delivery	1 hour
Unload and Prepare for Return	2 hours
Flight Return	1 hour
TOTAL	7 hours

Therefore, a gondola should complete 834.2 missions annually. Assuming a maintenance ratio of .1 would allow 58.4 maintenance hours annually. This maintenance hour estimate is over 50% of the fabrication assembly time allotted for most concepts. Due to the relatively simple structure, local repairs by a mechanic should be permitted to complete a mission. The use of pinned or bolted connections on the side, end, and top frame members should permit local replacement by the user organization. Scheduled maintenance should be permitted on an annual basis. It is projected that local maintenance could be accomplished within 1 hour and support maintenance within 3 hours. Preventive maintenance such as painting and replacement of fasteners, as required, could be accomplished during annual maintenance. Except for the helicopter mode, the gondola and container experience similar damage from intermodal transportation, terminal handling, and environmental degradation.

INTERMODAL DAMAGE

Of all the transportation modes other than by helicopter, the maritime conditions appear to be the most severe. However, the load factors due to rail humping and fixed-wing crash survivability would be more severe than the helicopter mode. The maritime conditions which impose the most damage occur when the gondola is lashed above deck. This becomes particularly detrimental when the gondolas are stacked, with the higher stack imparting racking and rolling motions which could damage the structure. It should be noted that the crash survivability and rail humping load factors are not considered. These load factors are 9.0G and 25.0G respectively. If these extreme conditions were included in the design criteria, a substantial tare weight penalty would be imposed.

TERMINAL AND YARD DAMAGE

Terminal and yard handling is a major cause of damage experienced in the container industry. This frequently occurs when provisions are lacking for forklifting or gantry acquisition. Another frequent source of damage is puncture of thin-gauge materials. To avoid these pitfalls, the gondola has both forklift tineway and toplifting load points.

It is desirable to have both capabilities except where the gondola is utilized beyond the terminal areas. No thin-gauge materials such as sheet stock is utilized to avoid susceptibility to puncture, tear, etc., or where abrasion, erosion, and corrosion would cause a significant percentage reduction in load-carrying ability. Chemical conversion coatings and subsequent protective finishes should be used.

ENVIRONMENT

Environmental degradation provisions are inherent in the selection of the materials and the surface protection afforded by the design. It is assumed that the gondolas would operate in a marine environment at the climatic extremes of AR 70-38 categories 1, 2, 5, and 6. The choice of materials and judicious use of thin-gauge materials must be such as to avoid corrosive and thermal degradation. The gondola shall have no restrictions to preclude operation in extreme climatic or atmospheric conditions. Corrosion and abrasion are the two most active degrading elements acting on the equipment. In addition, the degradation to fatigue loads must be considered. True assessment of the fatigue loads can only be achieved by performing a flight strain survey. From such a survey the stresses and a predicted frequency of occurrence could be established. Analysis has addressed limit and ultimate load factors. In satisfying these extreme load conditions, the structure would have a significant fatigue life of several years. Using a dynamic load factor of 3.0 superimposed on a 1.5 ultimate safety factor should provide sufficient structure to carry high frequency but relatively low amplitude vibratory stresses.

PERSONNEL EFFECTIVENESS

Utilization of the pallet/gondola should improve personnel effectiveness when moving cargo by helicopter, slung externally. Previous evaluation strongly suggests that many vehicles and equipment were carried as single items or required complex rigging procedures. This imposed a severe payload efficiency penalty on the helicopter. In addition, it required the rigging and attachment time to occur four times to achieve full load capacity of the CH-47 and CH-54. While loading, rigging, and attachment times for nets are difficult to quantify, they are strongly suspected to be significantly greater than that for a single gondola load. Optimized use of the helicopter gondola system may best be exploited when operating from an APOD or rear position terminal serviced by a typical Terminal Transfer Co.[11] The gondola should not only promote manpower and helicopter efficiency, but minimize rigging errors resulting in damage to or loss of cargo. The gondola will either enclose the cargo or provide tie-down restraints at specified intervals. In addition, the load lift points will eliminate errors in judgement which frequently occur in rigging individual vehicles and equipment. Prescribed rigging and cargo restraining instructions should be carried out with minimal guidance at the Terminal Transfer Co.

When using the gondola in contingency tactical deployment of equipment and vehicles, the load should be inspected for proper restraint and distribution. This could be accomplished by anyone with the minimum knowledge of standard aircraft rigging practices. Utilization of the gondolas in rear areas to a point where they are introduced at CONUS shipments demonstrates a vast potential by avoiding the transfer of the cargo at each transportation mode interface.

The selected design concept utilizes standard aircraft tie-down restraints which permit the use of standard restraint hardware. In addition, the loading and unloading of the gondola is improved over normal containers due to quick-release pinned structure. Vehicles and equipment can be loaded similar to CONUS shipment of break-bulk cargo, thereby eliminating onboard rigging. The attendant reductions in manpower requirements and the efficiency of unloading should be demonstrated.

Personnel effectiveness should be demonstrated particularly by prerigged gondolas with multiple units of vehicles and equipment. This will eliminate individual item rigging. This factor becomes particularly important when off-loading equipment from ship to shore.

DESIGN CONCEPTS

Design concepts presented herein are those basic concepts which may be considered to encompass the significant design features discussed previously. Each concept category has several configurations that have common structural features which are resolved in one analysis for that category. The following concept categories are analyzed for structural integrity:

Rigid Base

Folding

Soft Base

From these three categories, several configurations were designed in obtaining one or more gondolas compatible with the payload capabilities of each of the three helicopters. Concepts considered are presented in Table 13.

TABLE 13

DESIGN CONCEPTS

TITLE	SIZE
Rigid Base	20' x 8' x 8'
Rigid Base (coupled)	40' x 8' x 8'-6"
Wood Pallet Gondola	20' x 8' x 8'
Single Post Rigid Base	8' x 8' x 8'
Rigid Base Lateral Outriggers	20' x 8' x 8'
Plastic Pallet Gondola	17' x 7' x 8'
Side Folding	17' x 7' x 8'
Folding	20' x 8' x 8'
Single Post Folding	8' x 8' x 8'
Folding Parallelogram	20' x 8' x 8'
Folding Floor Sections	20' x 8' x 8'
Side Floor Folding	20' x 8' x 8'
Soft Base	20' x 8' x 8'
Soft Sided	8' x 8' x 8'

DESIGN BRIEF

A brief narrative discussion of each of the concepts is presented to point out significant features which contribute to or detract from overall performance of the gondola concepts. Significantly, all the concepts utilize standard structural shapes of aluminum alloy 6061-T6. This choice of material achieved nearly the highest rating in strength to weight and cost of several material candidates rated in the section on Materials and Methods of Construction. Joints are riveted, bolted, or welded, with welded connections used sparingly to avoid the strength reduction. Attachment fittings are both cast steel and aluminum alloys. In satisfying the reliability and maintainability, the gondola is conceived using rugged structural shapes that have a high resistance to mishandling, which is typical of cargo transfer operations.

In other concepts, relatively inexpensive pallets or nets were utilized to accommodate replaceability. In general, the concepts embody ruggedness for long life or replaceability at low cost.

RIGID BASE (20-x-8-x-8-ft)

This unit provides a 20-x-8-ft continuous, uninterrupted floor and volume. Four lift points are located coincidental with the ISO corner fittings. The unit can be transported by all surface modes incidental to the maritime container. It could be transported by fixed wing when used in conjunction with the 463L pallet as a slave. Two units may be connected at their sides to develop sufficient capacity for the HLH.

RIGID FLOOR (40-x-8-x-8½-ft)

Similar to the basic 20-ft-long rigid base, this concept connects two 10-ft end sections to a 20-ft center body. The height was increased to provide sufficient cubic capacity. The end connections are accomplished with a standard ISO fitting. The advantage of the 40-ft length is desirable to develop payload capacity of the HLH and for transporting vehicles. It is compatible with all surface modes of transportation and could be delivered by fixed wing using the 463L pallet as a slave.

WOOD PALLET GONDOLA (20-x-8-x-8-ft)

This concept has some of the construction features of the 20- and 40-ft-long rigid-based gondolas, but it integrates a standard wood pallet as a part of the floor surface. Preloaded pallets can be placed on the gondola structure. The base structure becomes somewhat heavier, but its utilization of the basic wooden pallet should prove to be highly effective. It could also be coupled on the side to achieve capacity near that of the HLH.

SINGLE-POST RIGID BASE (8-x-8-x-8-ft)

This concept features a rigid base with a removable center post which allows the empty base to be stacked for empty return. Although the unit does not have the single capacity of any of the helicopters, it can be piggy-backed to achieve near capacity of the CH-47 and CH-54 helicopters. It allows two-point distribution for supplying smaller units.

RIGID BASE - OUTRIGGER SUPPORTS (20-x-8-x-8-ft)

This concept has a floor structure similar to the 20- and 40-ft rigid-base gondolas; however, the side racking loads were reacted by a retractable outrigger support. This method proved to be impractical for the high reaction load and was rejected. Since the lift points were located at the quarter span, the other alternative was to place a diagonal brace across the lateral span, which would encumber the free areas. Later iterations of the design proved to have less tare weight when the side frame was continued to the end.

REMOVEABLE PLASTIC PALLETS (17-x-7-x-8-ft)

This concept was designed around a commercially available polystyrene pallet. The support structure is similar to that used for the wood pallet. It was initially conceived to support the pallet about its edge, which proved to be inadequate. However, with more support structure and added weight, the pallet could be utilized. The advantage of the plastic pallet is its stackability and potentially lower life-cycle cost than that of the wooden pallet.

SIDE FOLDING (20-x-8-x-8-ft)

This concept allows the sides to fold over the base and eliminates loose side parts when transported empty. This type of side structure could be utilized on any of the rigid-base concepts, with some modification required on the 40-ft length.

FOLDING BASE (20-x-8-x-8-ft)

This gondola concept allows the gondola to be stowed to nearly 25% of its deployed capacity by unpinning the end diagonal bracing. Three of the empty units can be connected in the folded configuration and transported on a fourth for empty return. The floor system aside from the hinged cross member is similar to the basic 20- and 40-ft-long gondolas.

SINGLE-POINT FOLDING (8-x-8-x-8-ft)

This concept folds about a center post to slightly over 3-x-8-ft and can be stowed in approximately 5% of its load capacity. Its low stowage density would allow it to be carried as internal cargo in the CH-47. Two of these units slung in piggyback would provide near payload capacity of the CH-47. However, due to the center post, the unit has limited equipment utility and no vehicle transport.

PARALLELOGRAM FOLDING (20-x-8-x-8-ft)

A parallelogram folding concept has two salient features which become inefficient for structural integrity. It requires a longitudinal center member about which a single-point hinge must rotate. Since it is both a tension and compression pivot point, it is more expensive than a horizontal hinge which is kept in tension. The center longitudinal member and the vertical hinges add weight and cost and degrade reliability, disadvantages which are not appreciably offset by its stowability over other concepts.

BASE SIDE AND END FOLD (20-x-8-x-8-ft)

The side and end folding concept offers improved stowability when empty. However, its load lift points occur over the floor area, which precludes the transport of vehicles and many equipment items. The use of additional members to accomplish folding further detracts from its reliability and payload effectiveness. In summary, the encumbered floor and free volume severely handicap its effectiveness.

SIDE FOLDING (20-x-8-x-8-ft)

This concept allows for folding the sides over the center section to reduce stowage. It has growth potential to double the floor width to provide capacity near that required for the HLH. The concept again encumbers the floor and the desired free internal volume. Little or no advantage is achieved for weight reduction or empty stowage by the folding side struts since the structure requires two longitudinal members. As shown in the analysis, folding, cantilevered, load strut structure is less efficient than a rigid floor. There is no distinct advantage for this concept.

SOFT BASE GONDOLA (20-x-8-x-8-ft)

The soft base concept is in effect a rigidized net which will contain cargo similar to a net but would virtually eliminate induced crushing of the loads. The structure base members are pinned, to which netting is attached. The base is attached to the upper acquisition structure by cable or chain. The structure could carry all previously netted loads and equipment. An on-site floor could be overlayed with planking or plywood to facilitate other equipment. Its ease in fabrication, low cost, and some weight savings are advantages over rigid and folding base concepts. However, it has limited intermodal capability and cannot transport vehicles.

SOFT BASE ERECTOR (8-x-8-x-8-ft)

This concept is an attempt to utilize inexpensive nets but to eliminate the undesirable crushing loads. The base and upper structure are rigidized by standard structural members to support the net. Since the size is 8-x-8-x-8-ft, provisions are made to couple two together, providing near capacity for the CH-47. To minimize upper support structure, a sling leg is required at each corner. The soft sides allow stowage to approximately

15% of its deployed volume. The unit can be forklifted and has limited intermodal capability.

CONCEPT EVALUATION

The above design concepts were rated by a comparative evaluation system which weighted the various features to accumulate 100 points maximum. The evaluation committee was composed of the project engineer, designers, and an analyst who were familiar with the design goals of the study. The rating system is presented below.

CONCEPT EVALUATION COMPARATIVE/WEIGHTED FACTORS (100-POINT TOTAL)

1. Design and Payload Acquisition (15 points)

   Three points for the following features:

   1. Provides cube capacity over continuous floor surface
   2. Interior unencumbered by support structure
   3. Simplest structure configuration
   4. Ease in tie-down restraint
   5. Multipoint attachment

2. In-flight Stability (15 points)

   Three points for the following features:

   1. Provides two or more lift points
   2. Lift point(s) above CG
   3. Least aerodynamic effect (drag)
   4. Low drag, high porosity when empty
   5. Permits quarter span CG travel

3. Interface Compatibility (15 points)

   15. Compatible with all interfaces of the supply network
   10. Excludes certain-interfaces of the supply network
   5. Compatible with helicopter mission only

4. Logistical and Technical Mission Requirements (10 points)

   10. Satisfies three helicopters
   6. Satisfies two helicopters only
   2. Offers limited capability

5. Production Costs (10 points)

   10. Lowest cost of all concepts
   8. In first quartile of cost ranking
   6. Median cost of all concepts

4. In third quartile of costs of all concepts
2. Highest cost of all concepts

6. <u>Weight</u> (10 points)

10. Highest payload per unit tare weight
5. At or near median of all concepts
0. At or near heaviest

7. <u>Personnel Efficiency</u> (10 points)

10. Least time per unit cargo load
8. In first quartile of time consumed of all
5. Median time, all concepts
2. In third quartile, all concepts
0. Highest time of all concepts

8. <u>Support Systems Compatibility</u> (5 points)

5. Can be integrated into supply system with minimal peripheral equipment
3. Requires limited introduction of support equipment
2. Capable of modification but compromises utility
0. Limited compatibility

9. <u>Reliability and Maintainability</u> (5 points)

5. Very reliable, easily maintained
3. Reliable with moderate maintenance
2. Reliable but has vulnerable components
0. Potentially unreliable, requiring frequent maintenance

10. <u>Environmental and Climatic Limitations</u> (5 points)

5. Suitable for all weather operations
2. Suffers degradation due to corrosive and abrasive degradation
0. Potentially unsuitable in climatic extremes

TABLE 14
COMPOSITE EVALUATION MATRIX

CONCEPT	EVALUATION FEATURE										
	1	2	3	4	5	6	7	8	9	10	TOTAL
SK 78001900	12	12	15	6	10	5	10	5	5	5	85
SK 78001901	12	12	15	10	6	5	8	5	2	5	83*
SK 78001902	9	12	15	10	8	5	10	3	2	2	76
SK 78001903	3	9	5	6	8	10	8	5	3	5	62
SK 78001904	9	9	15	10	2	0	8	5	3	5	66
SK 78001905	12	12	15	10	8	0	10	3	2	5	77
SK 78001906	9	12	15	10	6	5	5	5	3	5	77
SK 78011900	12	12	15	10	6	5	8	5	3	5	78
SK 78011901	6	9	10	6	8	10	5	5	5	5	69
SK 78011902	6	9	10	10	4	5	2	5	3	5	59
SK 78011903	ø	9	15	10	4	5	2	3	3	5	56
SK 78011904	ø	9	15	10	4	5	2	5	5	5	60
SK 78021900	12	9	10	10	8	10	5	5	2	2	73
SK 78021901	9	12	5	6	8	10	8	5	2	2	67

* Concept SK 78001901 was selected due to its utilization for all three helicopters (CH-47, CH-54, and HLH) plus potential usage with UTTAS. This overwhelming characteristic outweighs its second-place scoring in the evaluation system.

STRUCTURAL ANALYSIS AND LOADING CRITERIA FOR THE PREFERRED GONDOLA DESIGN

The gondola analyzed herein is that one which was determined to be the preferred concept. Although the concept placed second to another design, its capability to serve all three helicopters more than offset its evaluation ranking.

LOADS

The gondolas shall be designed and analyzed for the following gross weights and design load factors.

Gross Weights

GONDOLA	GROSS WEIGHT	GONDOLA WEIGHT
10 ft	15,000 lb	1,432 lb
20 ft	30,000 lb	2,525 lb
10 + 10	30,000 lb	2,864 lb
10 + 20 + 10	60,000 lb	5,420 lb

Each lateral end of the gondola units shall be designed structurally and dynamically for the various configurations and imposed loads.

Load Factors

The lateral and longitudinal load factors in the table below are combined with a 1.0 g vertical load factor.

TABLE 15
GONDOLA LIMIT DESIGN LOAD FACTOR[3]

Direction of Load	Terminal Operations	Fork-lift	Marine	Highway	Rail	AIRCRAFT Fixed[5] Wing	AIRCRAFT Rotary[4] Wing
Downward	2.0	1.25	1.8	1.7	1.5	3.0	3.0[1]
Upward	0.0	0.0	0.0	0.0	0.0		
Lateral	0.2	0.0	0.6	0.1	0.3	1.5	.6[2]
Longitudinal	0.7	0.0	0.6	0.7	1.8	1.5	.6[2]

[1] Reference [4]

[2] Equivalent to 30° swing on vertical attachment sling.

[3] All load factors, except for aircraft, are from Reference [25], except as noted.

[4] Suspended from four top corners of 20-ft gondola when the gondola segments are coupled for the 40-ft gondola.

[5] Reference [5]

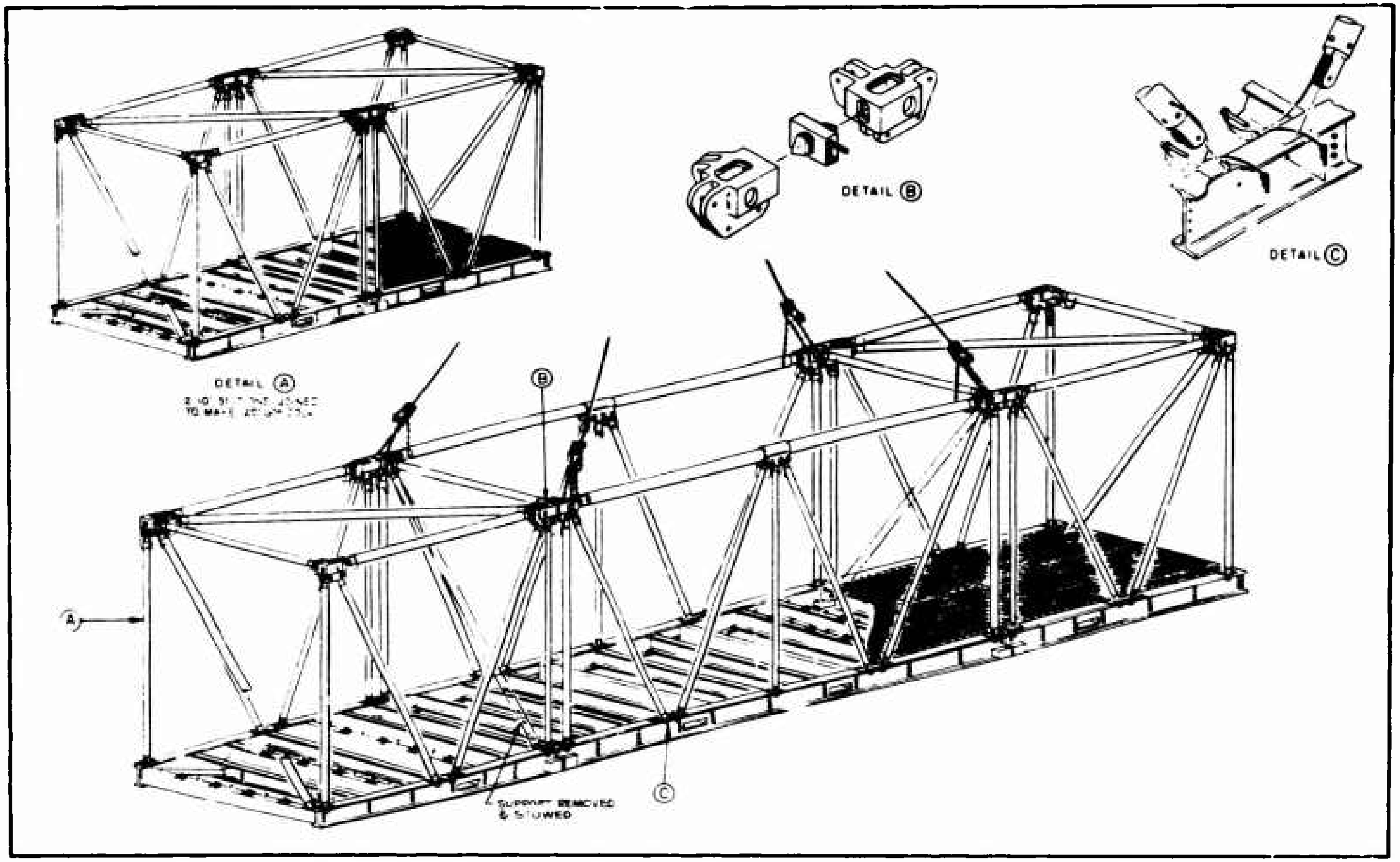


Figure 15. 10-x-20-x-10-Ft Coupled Gondola Assembly.

Corner Fitting Ultimate Load Factor

The corner fitting ultimate load factors were obtained from Reference 25 and are listed below:

DIRECTION	LOAD FACTOR (ULTIMATE)
Longitudinal	2.85
Lateral	2.89
Vertical	6.55

The above loads are to be applied independently to the corner casting only.

Deck Loads

The gondola deck shall be designed to carry the maximum cargo weight times the maximum design load factor evenly distributed over its total surface area. It shall also be capable of carrying the following vehicular loads (on the open grating decked gondola only). A 1.3 impact factor will be applied to all wheel loads.

TABLE 16
VEHICLE AXLE LOADS

WEIGHT	AXLE			
	FRONT	INNER	REAR	TOTAL
Curb Weight	5580	3960	3960	13,500
Payload	350	3075	3075	6,500
Total	5930	7035	7035	20,000
Tire Loading	2965	1759	1759	

Tire Contact Area: 5.6 x 5.6 inches
Max. Tire Load: 2965 x 1.3 = 3855 (impact)
Front Axle Width: 67.75 inches
Rear & Mid Axle Widths: 70.25 inches

Forklift

Forklift Weight: 4200 lb
Capacity: 2000 lb
Total ------------- 6200 lb

85% of weight is on drive axle = 5270 lb
30% of impact load on each wheel = 3425 lb
Tire contact area = 4.5 x 4.5 inches

Stacking

The gondolas shall be capable of withstanding loads imposed by stacking the gondolas six high at their maximum gross weights. The bottom container is assumed to be supported equally by the four lower corner fittings. The 1.8 g downward load factor shall be applied to the stacked gondolas.

Racking

The gondolas shall be capable of withstanding racking loads applied longitudinally or laterally at the upper corners and restrained by the lower corners. This load shall be .6 times the container gross weight. A 1.0 g downward load is also acting on the container during the racking load.

Tie-Down Rings

The cargo tie-down rings and immediate backup structure shall be capable of withstanding 5,000 lb vertical or 5,000 lb 30° from the vertical in any direction.

CRITERIA

General

All loads presented in the loads section shall be considered limit loads, unless specified otherwise; and shall be multiplied by an ultimate load factor of 1.5 in the stress analysis. The margin of safety calculation shall be based on ultimate allowable stress values of the material for a zero or greater margin of safety unless a 15% margin of safety based on yield values of the material is more critical.

$$\text{M.S.} = \frac{\text{Ultimate Material Allowable}}{\text{Ultimate Stress Level}} = -1 \geq 0$$

-or-

$$\text{M.S.} = \frac{\text{Yield Material Allowable}}{\text{Limit Stress Level}} = -1 \geq .15$$

Joints

All multi-attachment joints or eccentrically loaded joints shall use a 15% fitting factor on both the limit loads and ultimate loads. The rules of the preceding section shall apply in all cases.

Material Allowables

The following material allowables, with the exception of the weld allowables, are from Reference 9.

6061-T6 Extrusion QQ-A-200/8

F_{tu} = 40,000 psi

F_{ty} = 36,000 psi

F_{cy} = 38,000 psi

F_{su} = 29,000 psi

F_{bru} = 69,000 psi e/D = 1.5

F_{bru} = 89,000 psi e/D = 2.0

F_{bry} = 58,000 psi e/D = 1.5

F_{bry} = 65,000 psi e/D = 2.0

$E = 9.9 \times 10^6$ psi

$E_c = 10.1 \times 10^6$ psi

6061-T6 Drawn Tube WW-T-700/6

F_{tu} = 42,000 psi

F_{ty} = 35,000 psi

F_{cy} = 34,000 psi

F_{su} = 27,000 psi

F_{bru} = 67,000 psi e/D = 1.5

F_{bru} = 88,000 psi e/D = 2.0

F_{bry} = 49,000 psi e/D = 1.5

F_{bry} = 56,000 psi e/D = 2.0

$E = 9.9 \times 10^6$ psi

$E_c = 10.1 \times 10^6$ psi

A356.0 T6 Aluminum Casting Class 1a MIL-A-21180

$F_{tu} = 38{,}000$ psi

$F_{ty} = 28{,}000$ psi

$F_{cy} = 28{,}000$ psi

$F_{su} = 27{,}000$ psi

$F_{bru} = 53{,}000$ psi e/D = 1.5

$F_{bru} = 68{,}000$ psi e/D = 2.0

$F_{bry} = 45{,}000$ psi e/D = 1.5

$F_{bry} = 50{,}000$ psi e/D = 2.0

$E = 10.4 \times 10^6$ psi

$E_c = 10.5 \times 10^6$ psi

Welded 6061 Tubes or Extrusions
(Reference: Reynolds Aluminum, "Structural Aluminum Design", Handbook, 1968, page 61.)

$F_{tu} = 27{,}000$ psi

$F_{ty} = 17{,}000$ psi

$F_{su} = .55\ F_{tu} = 15{,}000$ psi

$F_{bru} = 54{,}000$ psi

$F_{bry} = 34{,}000$ psi

Attachments

The majority of the attachments will fall under the "AN" category or MIL-B-6812, for non-corrosion-resistant steel fasteners.

Ultimate Loads:
Tensile = 125,000 psi
Shear = 75,000 psi

FASTENER DIAMETER (in.)	SINGLE SHEAR (lb)	TENSION (lb)
1/4	3680	3360
3/8	8280	8470
1/2	14700	15730
5/8	23000	25100
3/4	33150	37800

Stress Analysis - Discussion

The gondolas are constructed principally of 6061-T6 aluminum alloy. The material properties are presented in the previous section. All joints are bolted or pinned. The tube fittings of the superstructure and the tineway opening reinforcement in the side beam are welded, and appropriately reduced material allowables are used.

There are two types of gondolas: one 10 ft long and the other 20 ft long. They can be joined in various combinations:

10 footer alone
20 footer alone
20 footer = 10 + 10
40 footer = 10 + 20 + 10

The 40-ft configuration is picked up by the four corners of the 20-ft gondola in the center with the 10-ft gondolas cantilevered from the 20 ft. The 40-ft configuration is subjected to the critical load combinations; therefore, other combinations are not analyzed.

Superstructure Brace Loading

This section presents stick structure diagrams which represent loads in the brace members for various GONDOLAS, or combinations of GONDOLAS, and various conditions. Where the condition produces unsymmetrical loading, both sides of the gondola are shown. In some cases, the loads on the bracing are a function of the stiffness of the side beams. The following sections present these brace loads in the form of reactions from continuous span beam analysis.

In most cases the 40-ft gondola combination is critical by inspection, and only these cases are analyzed. The superstructure brace loads are summarized in Table XX.

One, two, or four helicopter attachment points may be utilized. For the case of a single pickup point, the sling lifting on the four corners of the 20-ft gondola induces an additional load into the bracing depending upon the sling angle. This loading is shown for the 3.0 g lift condition where the gondola may be picked up by one or by four points. Sidesway or endsway conditions are always picked up by four points and are assumed to produce approximately a 30° angle between the sling and the vertical, which is equivalent to .6 g lateral or longitudinal load factor.

3.0 G Helicopter Lift, 40-Ft Gondola

Gross Weight = 60,000 lb (15,000 + 30,000 + 15,000)
Limit Vertical Reaction = 3 x 60,000/4 = 45,000 lb

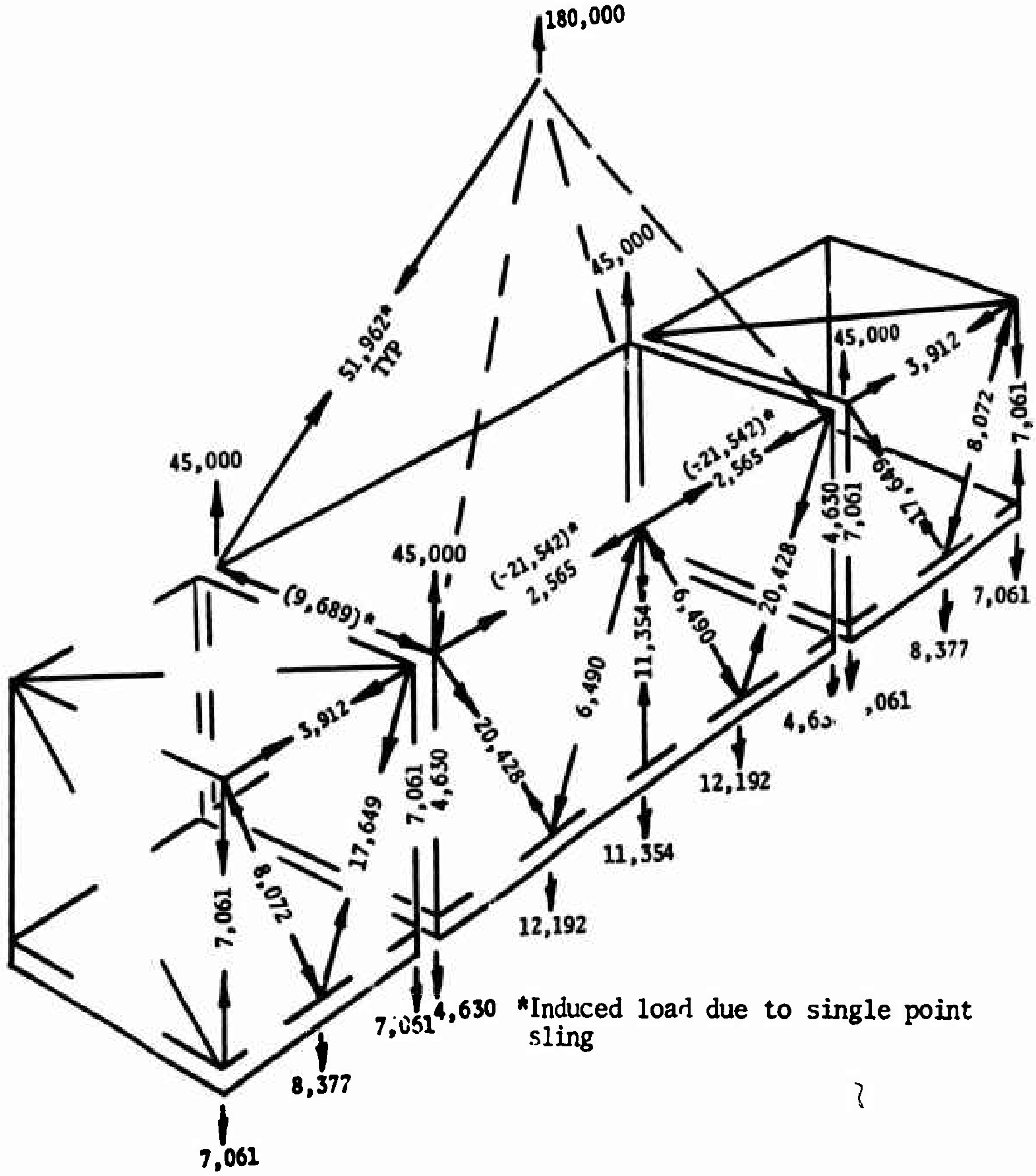


Figure 16. Brace Structure Loading (3G).

SINGLE-POINT SLING LOADING - INDUCED LOAD

Gondola Loads

Sling Angle = 30°

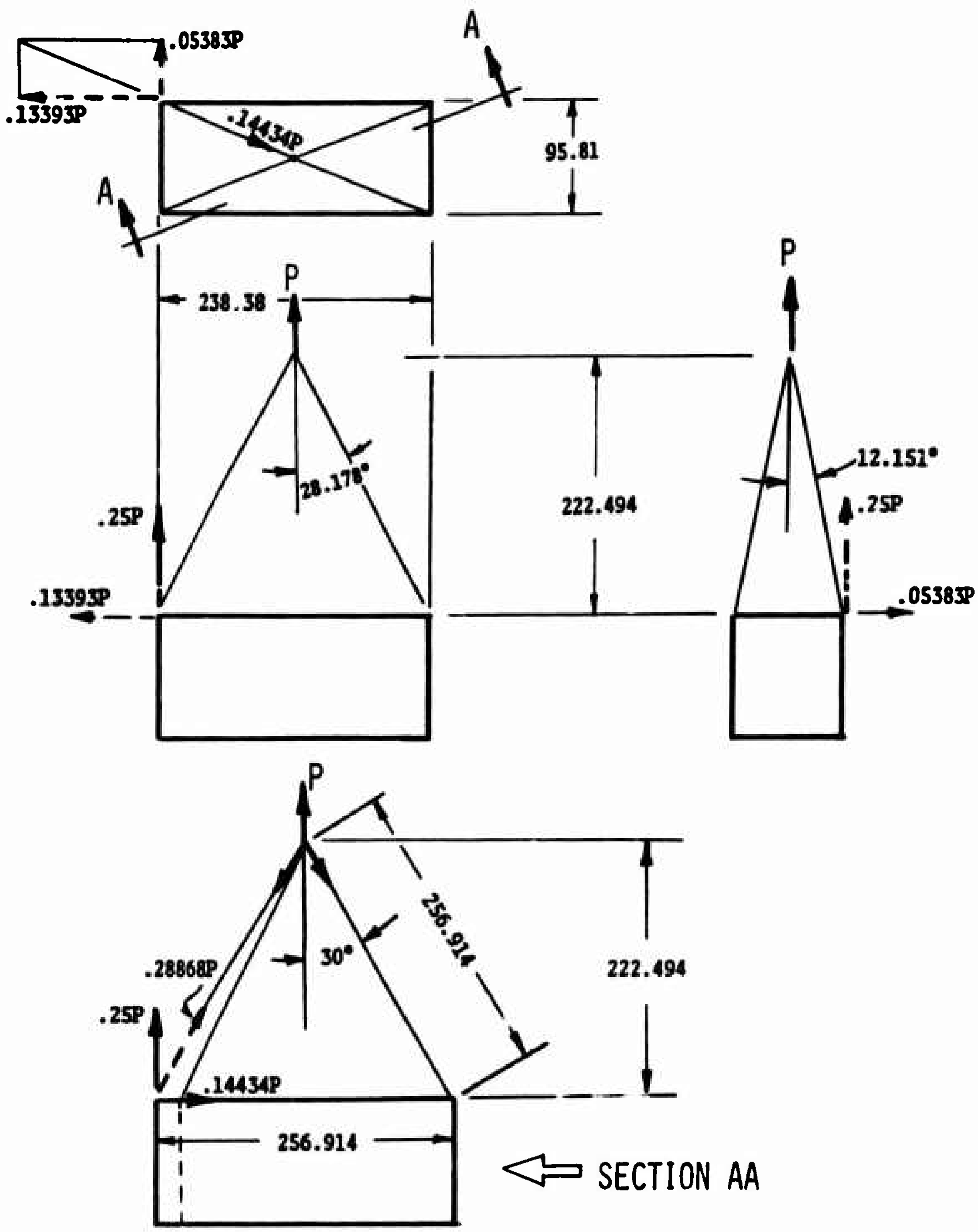


Figure 17. Sling Attachment Angles.

3.0 G Helicopter Lift, 20-Ft Gondola

Gross Weight: 30,000 lb
Limit Vertical Reaction = 3 x 30,000/4 = 22,500 lb

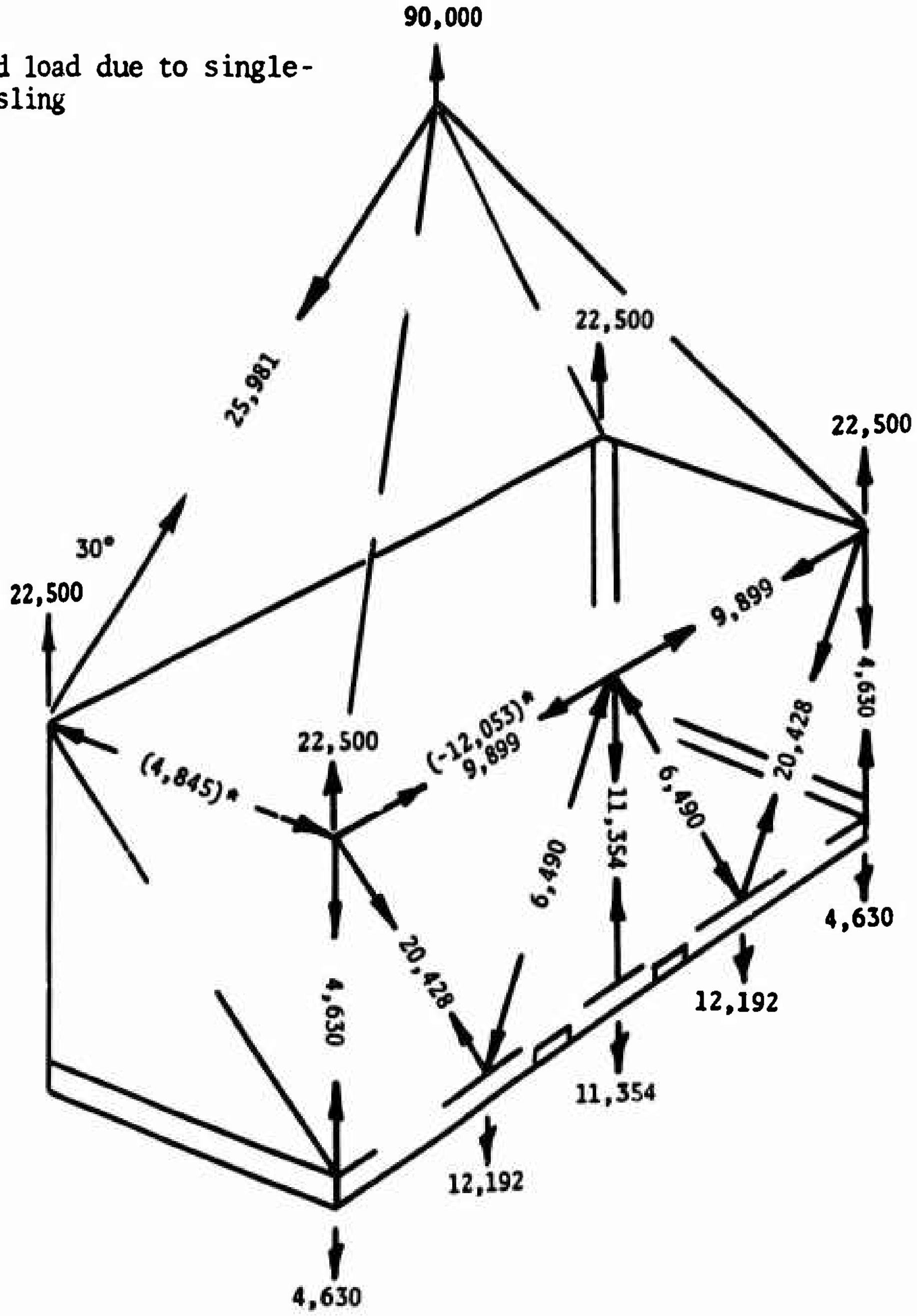


Figure 18. Brace Structure Loads (Center Section).

3.0 G Helicopter Lift, 40-Foot Gondola

60%:40% Load Distribution

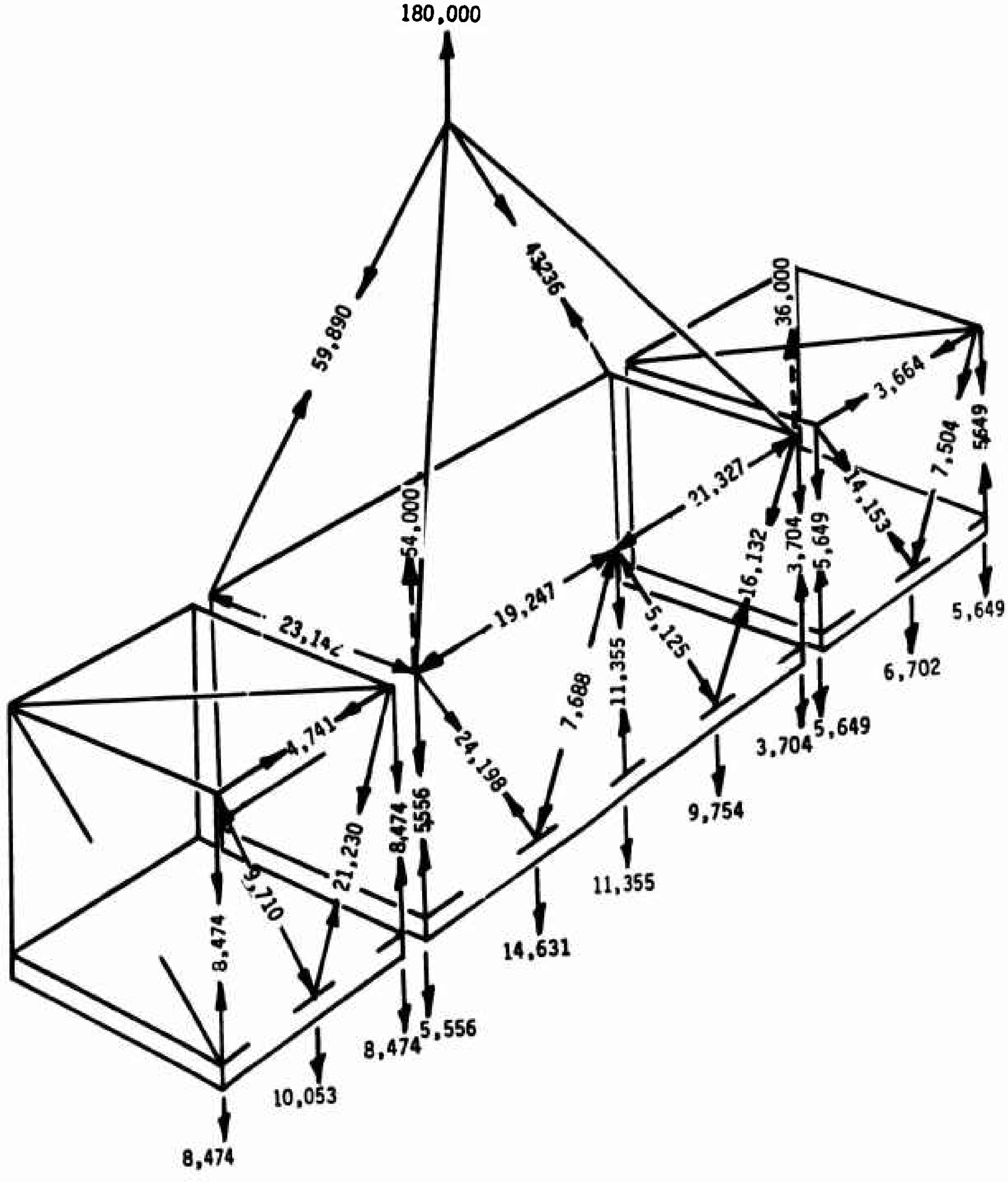


Figure 19. 60%:40% Load Distribution (lb).

1.25 G Forklift, 40-Ft Gondola

Gross Weight: 60,000 lb (15,000 + 30,000 + 15,000)
Forklift Tine Reaction: 1.25 x 60,000/4 = 18,750 lb/Tine/Beam

NOTE: The forklift tines must extend through both side beams.

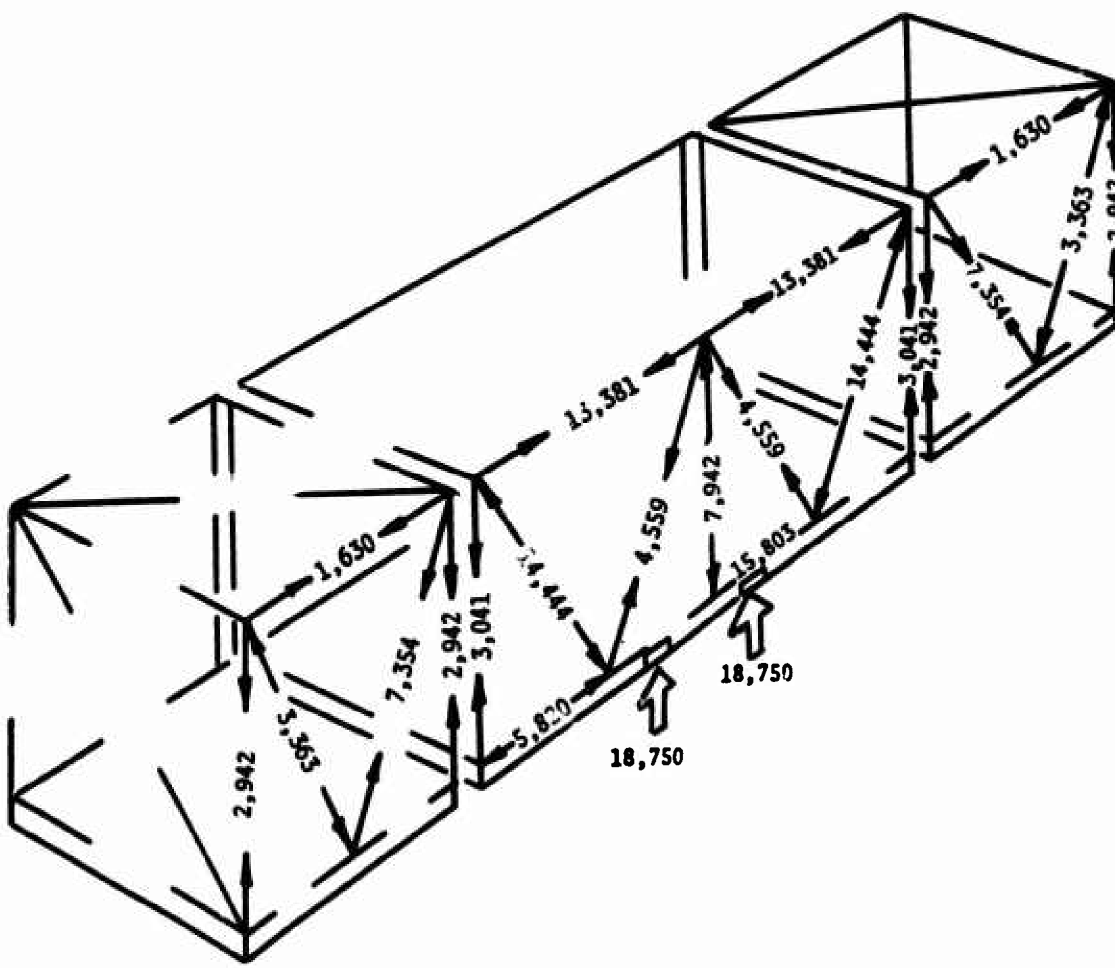


Figure 20. Forklift Loading.

.6 G Side Sway - Helicopter, 40-Ft Gondola/Far Side

Gross Weight: 60,000 lb (15,000 + 30,000 + 15,000)
Side Load = .6 x 60,000 = 36,000 lb
Vertical Load Factor = 1.0 G

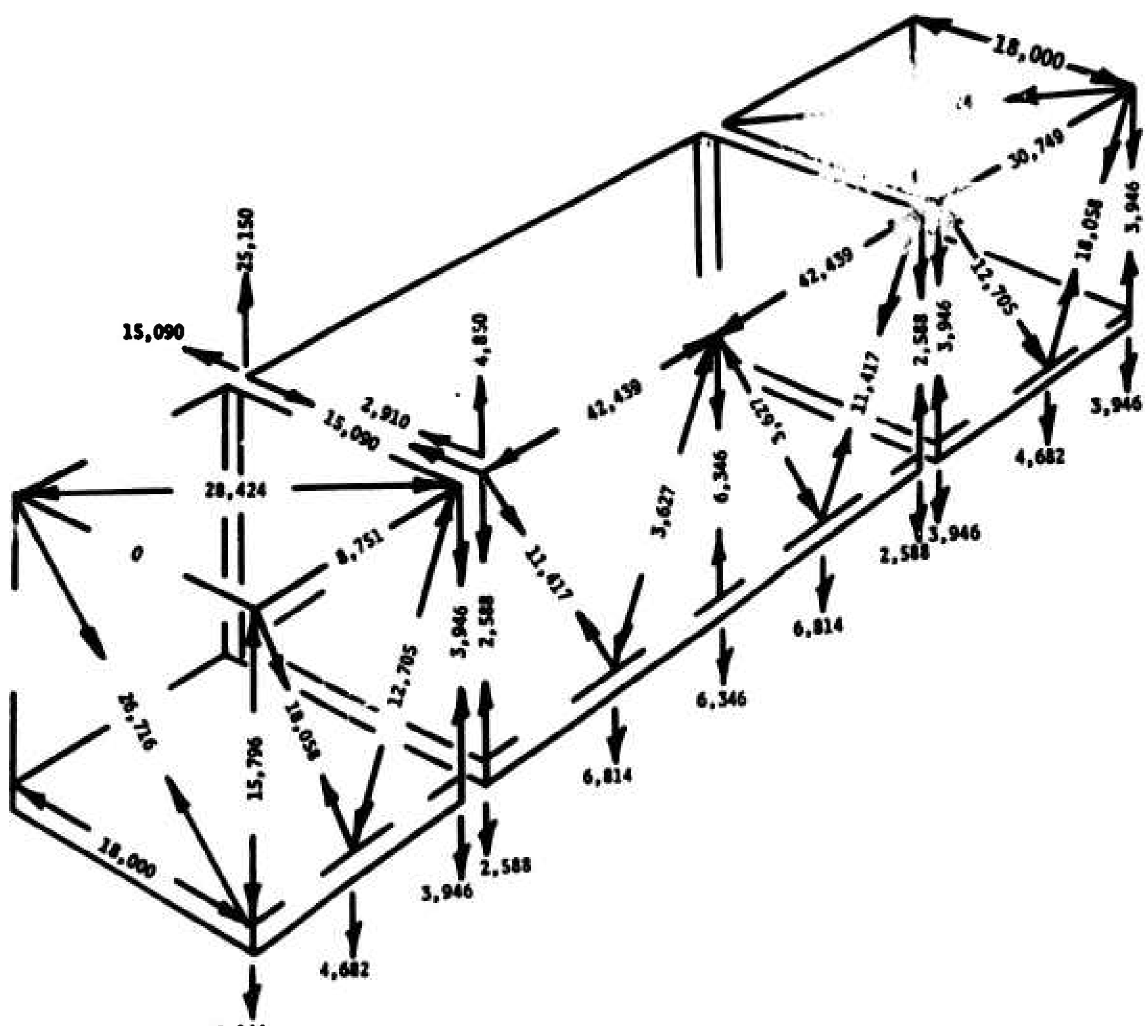


Figure 21. Side Sway Loading - Far Side.

.6 G Side Sway - Helicopter, 40-Ft Gondola/Near Side

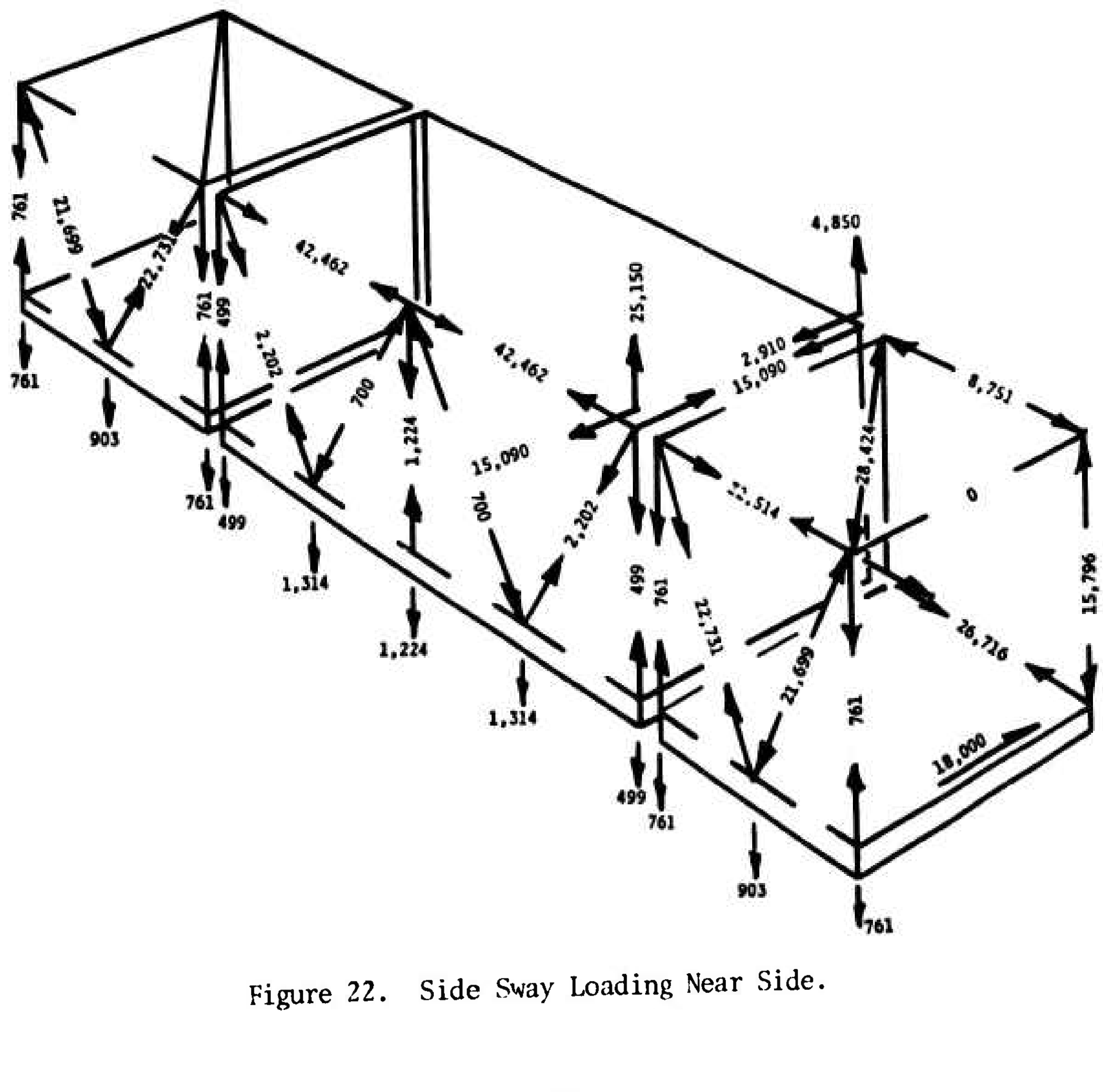
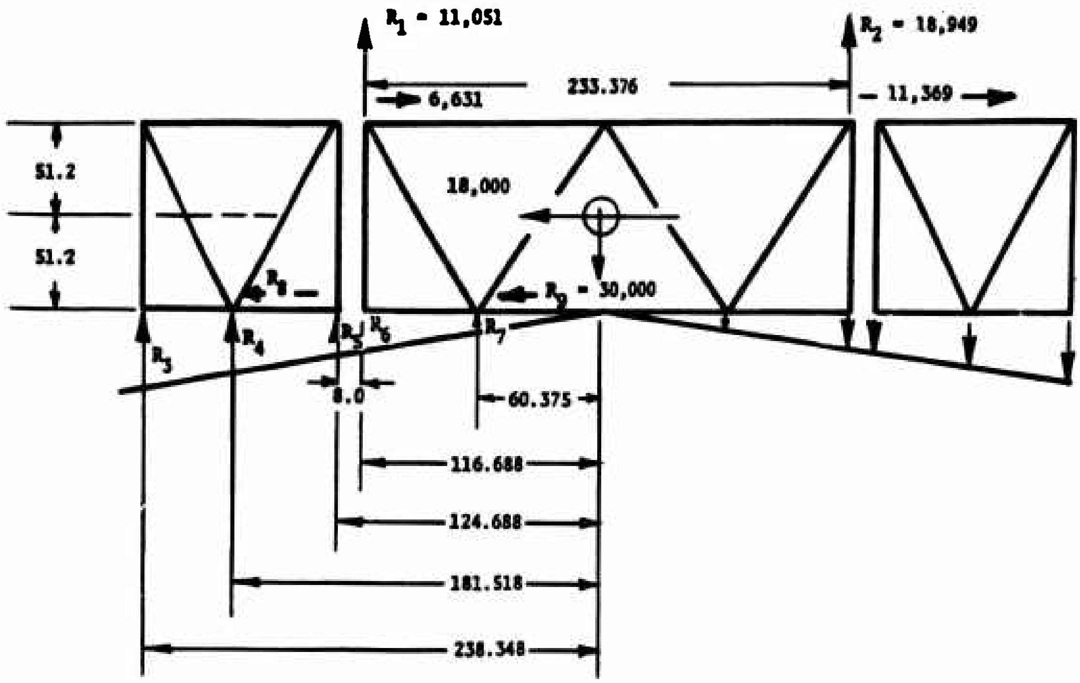


Figure 22. Side Sway Loading Near Side.

End Sway .6 G - Helicopter, 40-Ft Gondola



Floor Reactions to Cargo Moment Loading Only

$$M = 18,000 \times 51.2 = 921,600 \text{ in.-lb}$$

$$I = 2\,(238.348^2 + 181.518^2 + 124.688^2 + 116.688^2 + 60.375^2)$$
$$= 245,133$$

$$R_3 = \frac{Md}{I} = \frac{921,600 \times 238.348}{245,133} = 896 \text{ lb}$$

R_4 = 682 lb

R_5 = 469 lb

R_6 = 439 lb

R_7 = 227 lb

$$R_8 = \frac{18,000}{460.696} \times 113.66 = 4,441 \text{ lb}$$

$$R_9 = \frac{18,000}{460.696} \times 116.688 = 4,559 \text{ lb}$$

End Sway .6 G - Helicopter, 40-Ft Gondola

Gross Weight: 60,000 lb (15,000 + 30,000 + 15,000)
End Load = .6 x 60,000 = 36,000 lb
Vertical Load Factor = 1.0 G

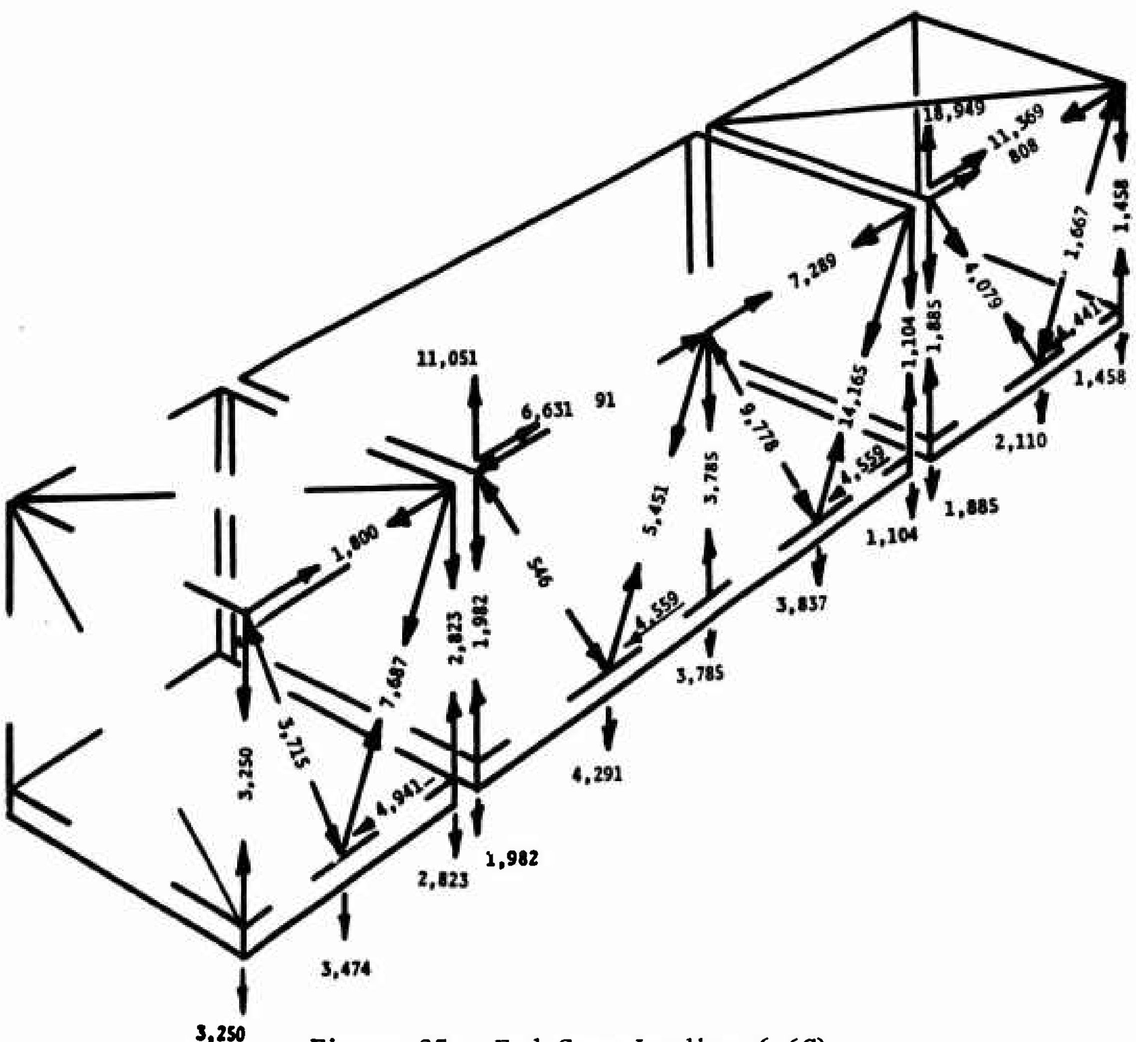
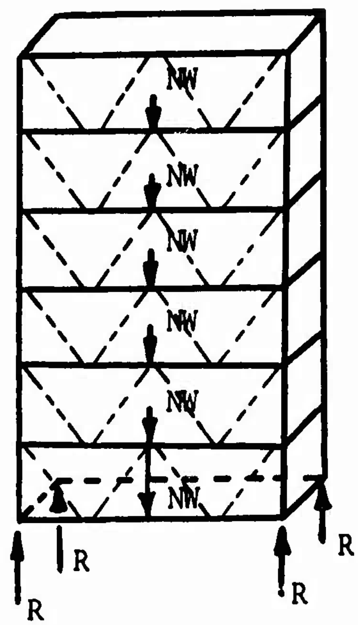


Figure 23. End Sway Loading (.6G).

Stacking Condition

Gondola stack is six high
Load Factor = 1.8 G
Gross Weight = 30,000 lb/20-Ft Gondola



NW = 1.8 x 30,000 = 54,000 lb

Stacking Condition.

$$R = \frac{6 \times 54,000}{4}$$

$$= 81,000 \text{ lb (limit)}$$

$$= 1.5 \times 81,000 = 121,500 \text{ lb (ult)}$$

$$\text{Max Corner Stanchion Load} = \frac{5 \times 54,000}{4}$$

$$= 67,500 \text{ lb (limit)}$$

Summary - Superstructure Limit Brace Loads

+ Tension
- Compression

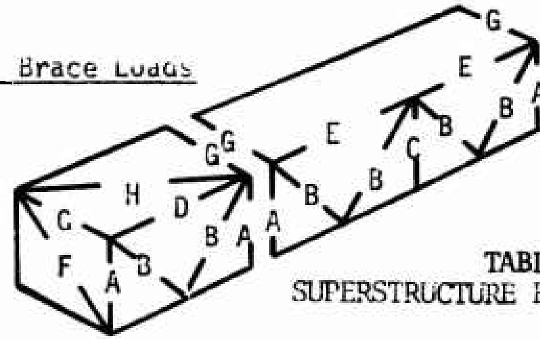


TABLE 17
SUPERSTRUCTURE BRACE LIMIT LOADS

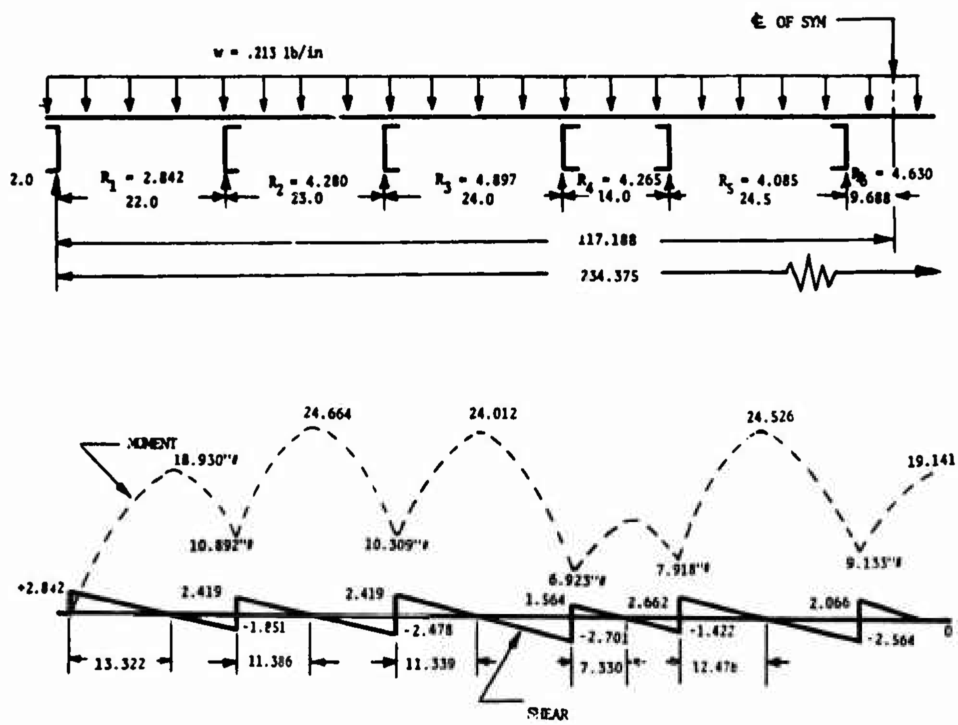
CONDITION	MEMBER							
	A	B	C	D	E	F	G	H
3.0 G Helicopter Lift	+7061	+20428 -8072	+11354	+3912 -10771	+2565 -21542	0	0 -9689	0
3.0 G Lift 60:40 Distribution	+8474	+24198 -9710	+11355	+4741	-18761	0	0	0
1.25 G Forklift	+3041	+7354 -14444	-7942	+1630	+13381	0	0	0
.6 G Sidesway Helicopter	+3946 -15796	+22731 -21699	+6346	+32514 -30749	+42462 -42439	+26716 -26716	+18000 -18000	+28424 -28424
.6 G Endsway Helicopter	+3250	+14165 -9778	+3785	+1800	+7289 -91	0	0	0
6 High Stacking	0 -67500	0	0	0	0	0	0	0
[illegible] Lift M54 Truck & Trailer	+[illegible]80	+29205 -17920	+2[illegible]913	+470	-25957	0	+8252	0

Unit Load Distribution - Deck to Crossbeams - 20-Ft Gondola

Unit Load = 50

w = 50/234.375 = .213 lb/in.

The following load distribution was determined by using the moment distribution method.



SHEAR AND MOMENT DIAGRAM

Figure 24. Shear and Moment Diagram - Deck to Crossbeam, 20-Ft Gondola.

Unit Load Distribution - Deck to Crossbeams - 10-Foot Gondola

Unit Load = 50
w = 50/113.66 = .4399

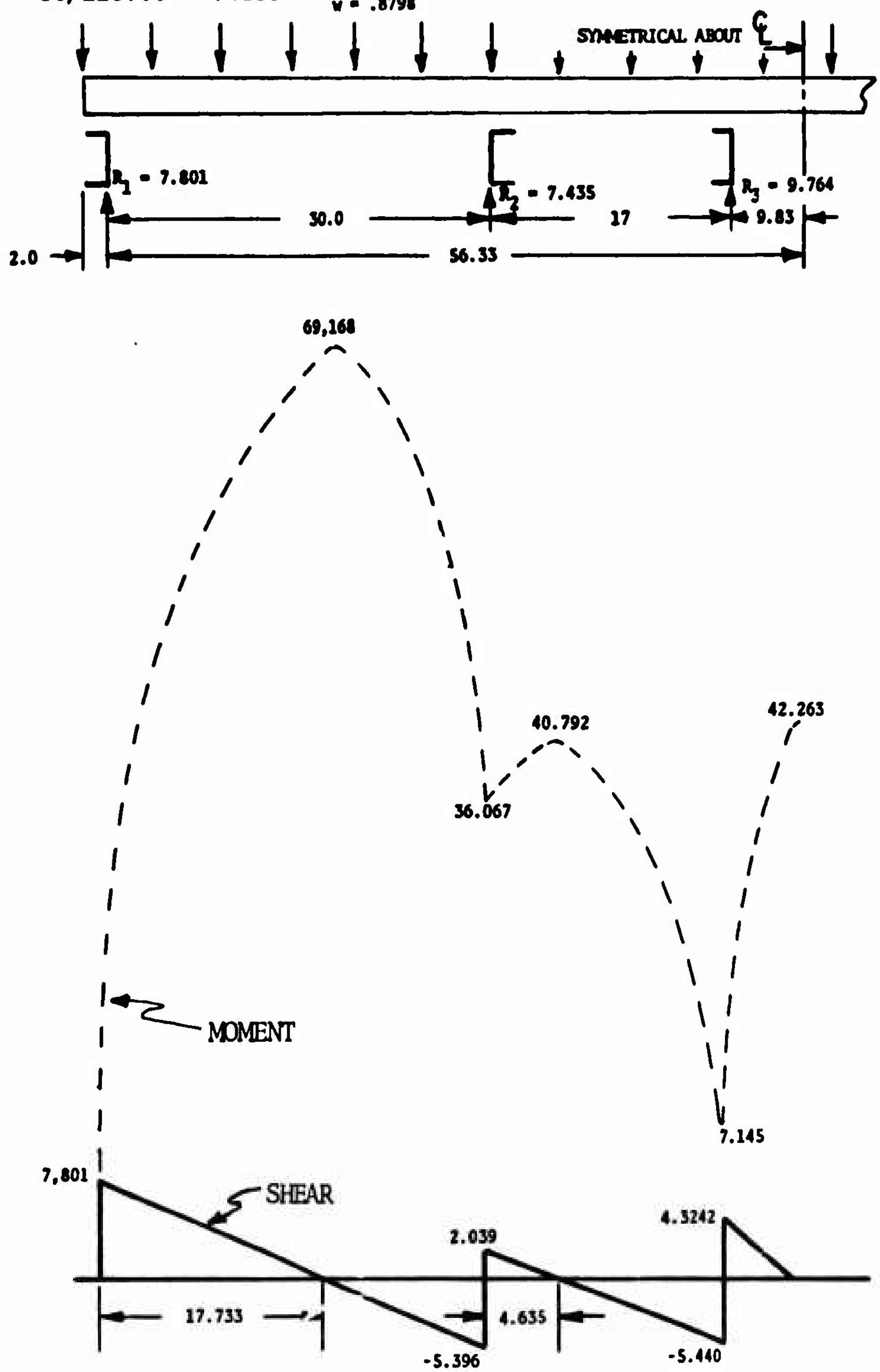


Figure 25. Shear and Moment Diagram - Deck to Crossbeam, 10-Foot Gondola.

Unit Distribution - Side Beams to Superstructure, 20-Ft Gondola

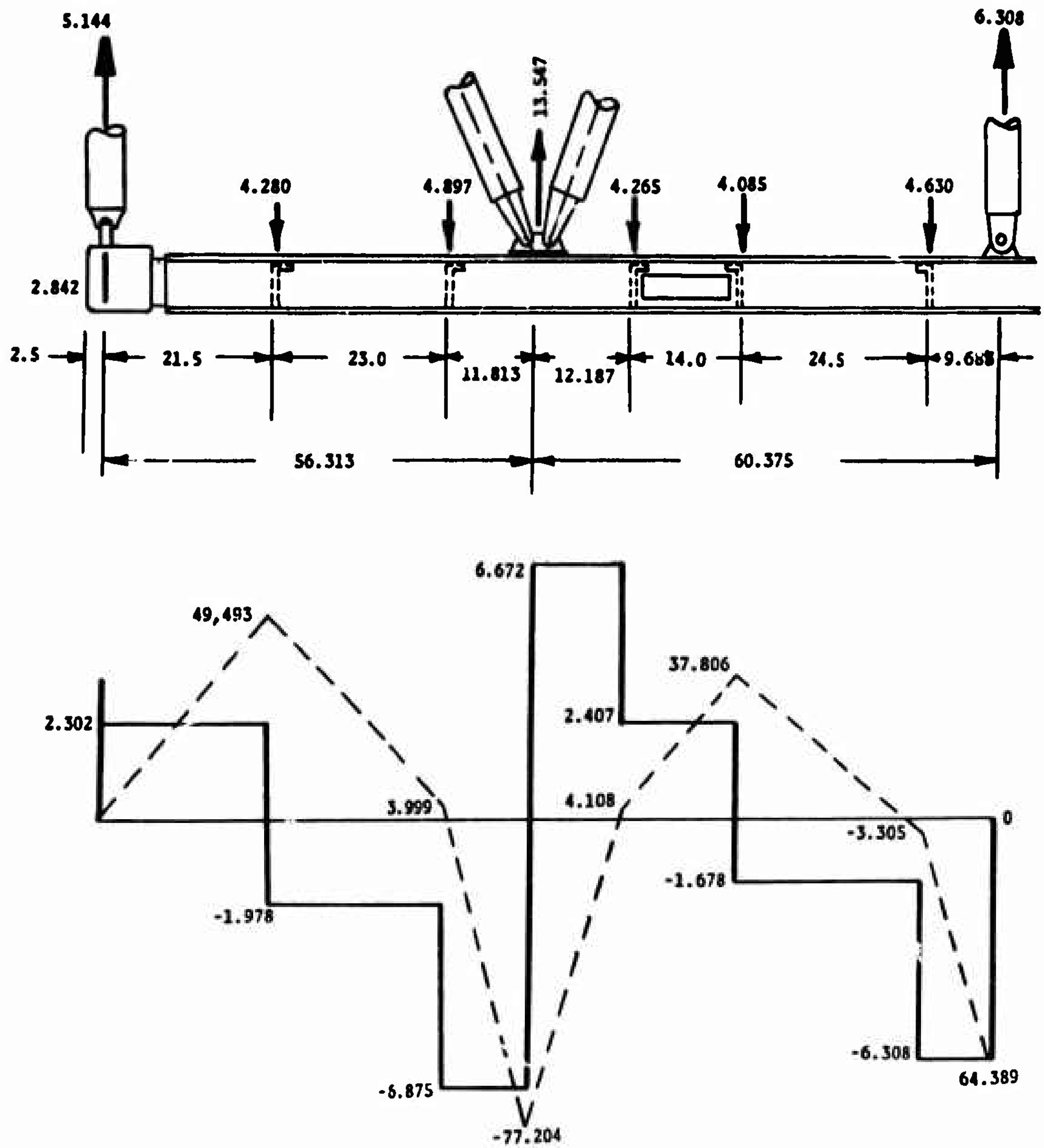


Figure 26. Shear and Moment Diagram - Side Beams, 20-Foot Gondola.

Unit Distribution - Side Beam to Supers ructure, 10-Ft Gondola

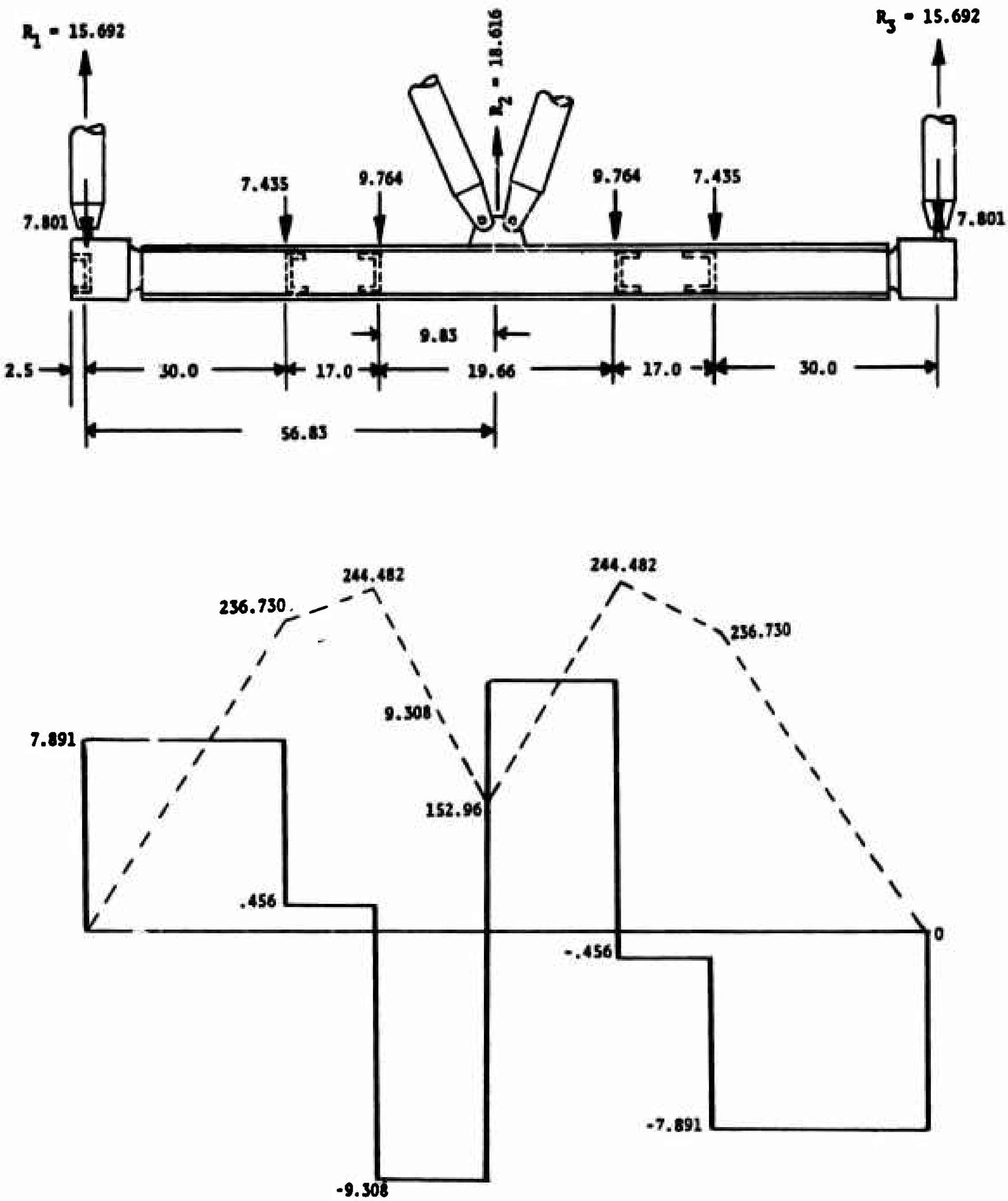


Figure 27. Shear and Moment Diagram - Side Beams, 10-Ft Gondola.

40-Ft Gondola Side Beam - Load Distribution

1.25 G Limit Forklift Condition

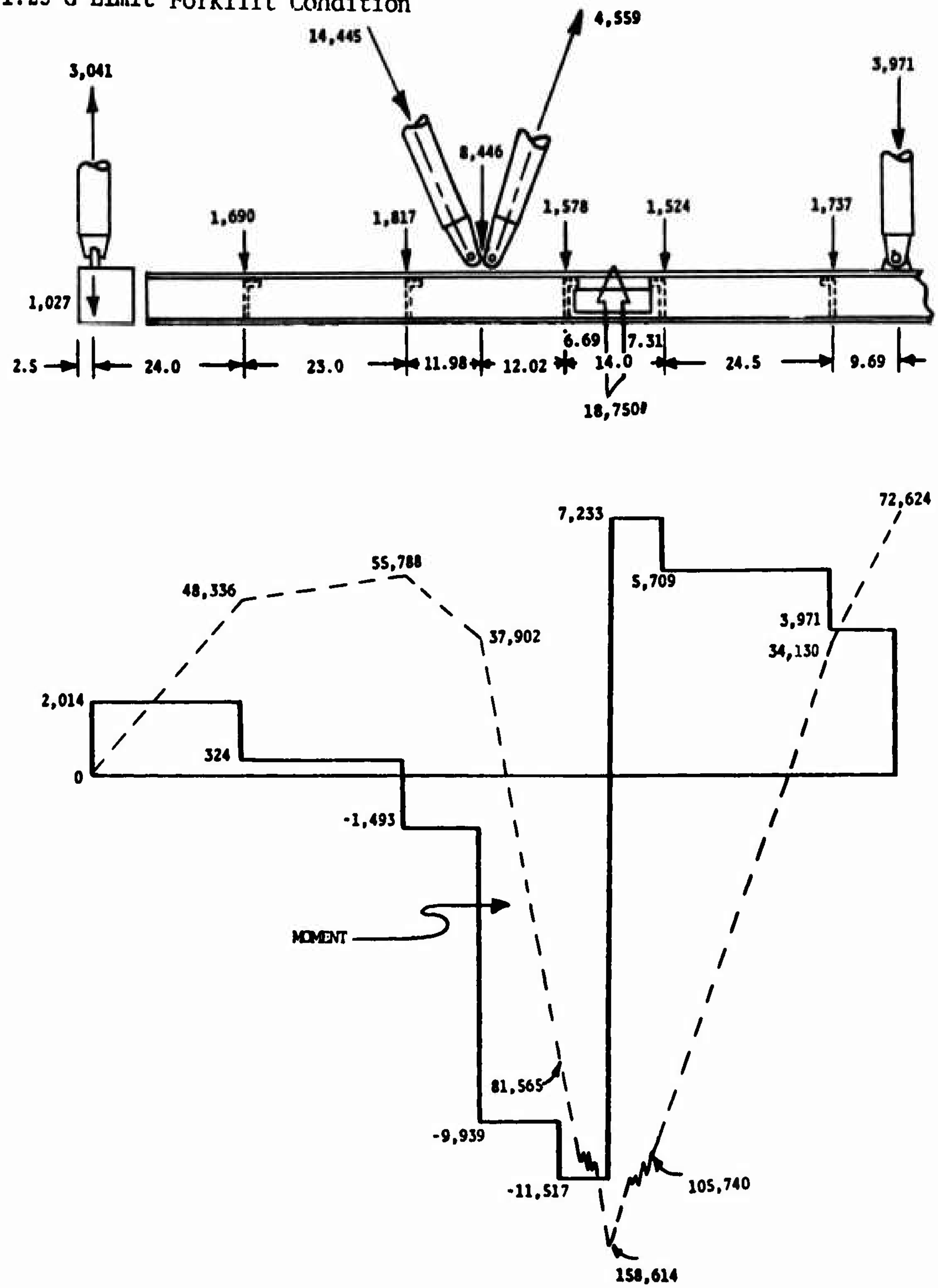
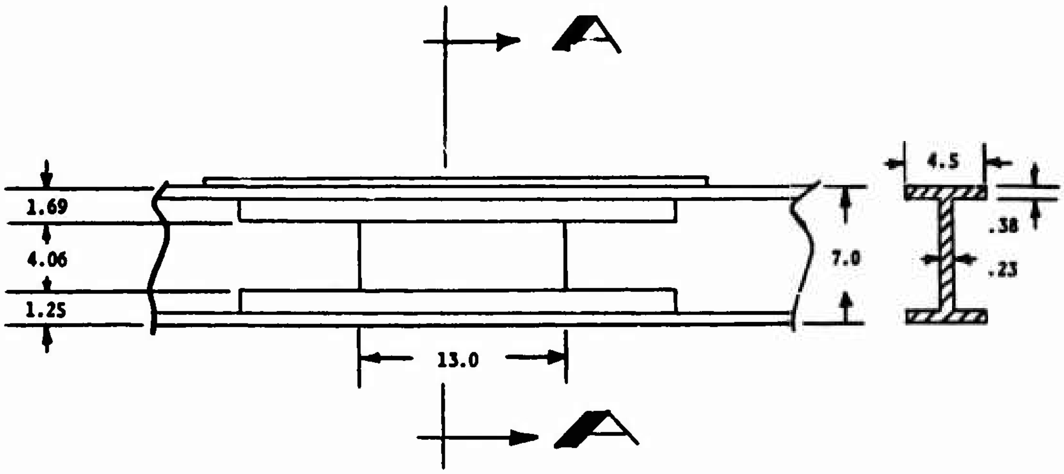


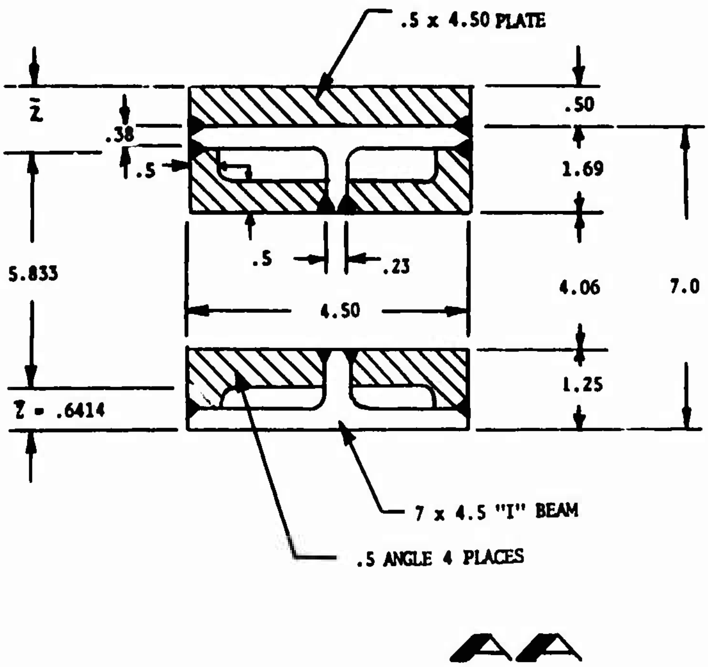
Figure 28. Shear and Moment Diagram - Forklifting, 40-Ft Gondola.

Side Beam Analysis

The 1.25 G limit forklift condition on the 40-ft-long combined gondola set is the critical loading for side beam bending at the tineway cutouts.



Side Beam With Tineway



Upper Cap

A = 7.2063 in^2
I = 3.66322 in^4
$\bar{Z}$ = 1.02516 in

Lower Cap

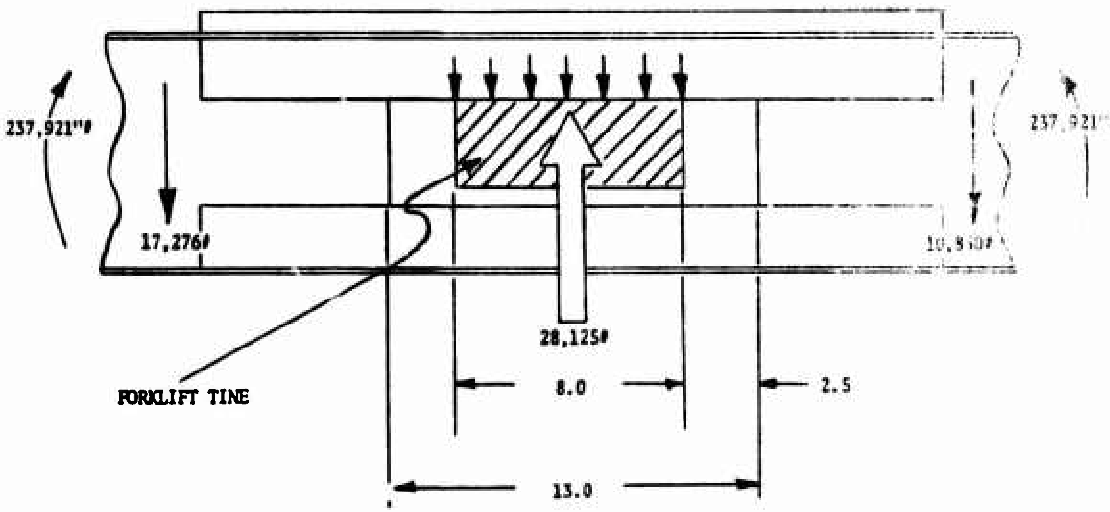
A = 4.4151 in^2
I = .71307 in^4
$\bar{Z}$ = .6414 in

Section Through Tineway Reinforcement

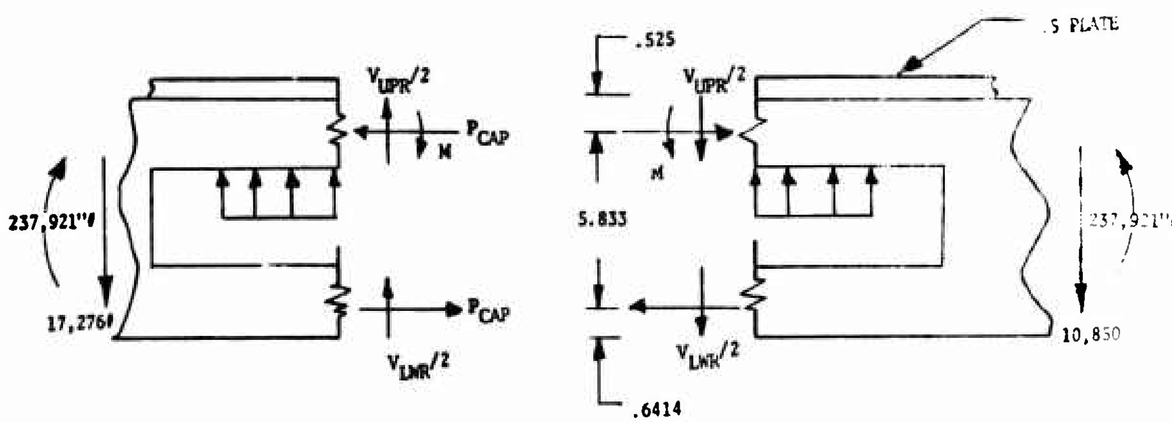
Figure 29. Tineway Analysis.

Load Distribution on Side Beam Tineway Opening

All loads presented below are ultimate.



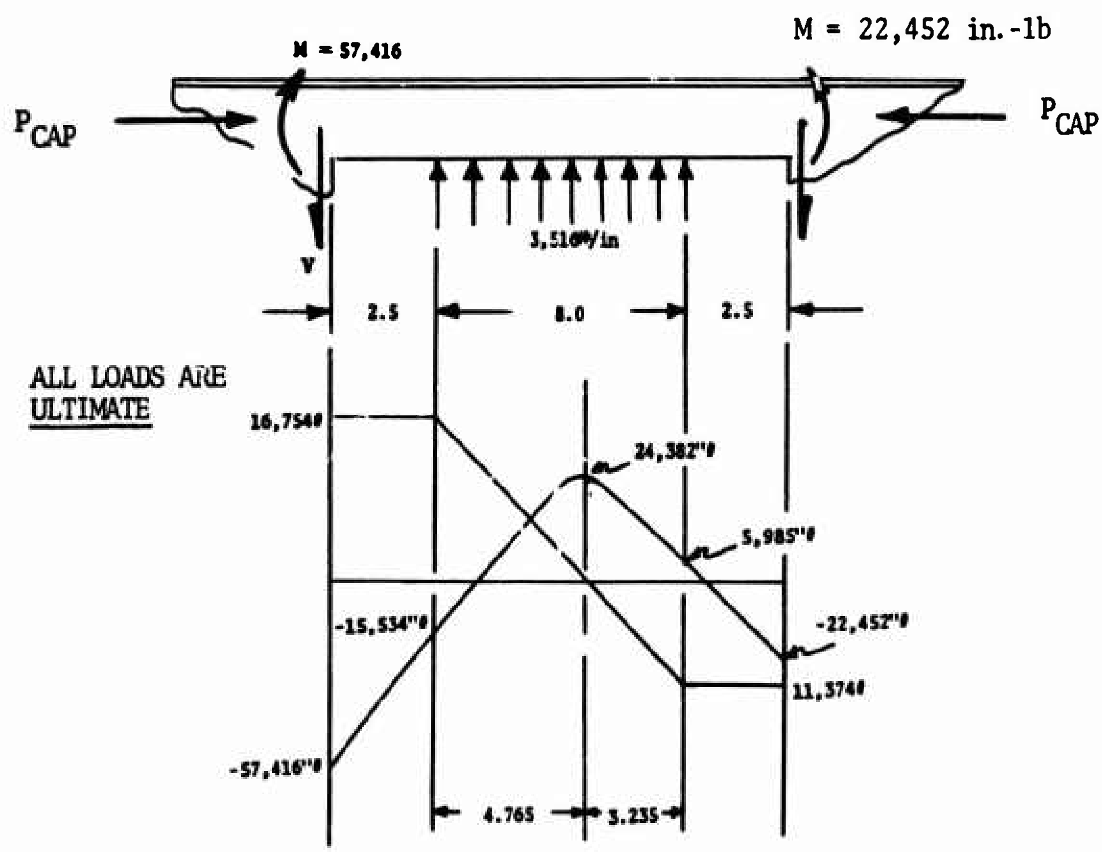
View of Loaded Tineway



Free Body of Tineway

Figure 29. Continued.

Shear/Moment Diagram - Upper Flange



Upper Cap

$$f_b = \frac{Mc}{I} = \frac{57,416 \times 1.165}{3.6632} = 18,260 \text{ psi}$$

$$f_a = \frac{P}{A} = \frac{40,790}{7.206} = 5,660 \text{ psi}$$

$$f_s = \frac{V}{A} = \frac{16,754}{7.206} = 2,325 \text{ psi}$$

$$f_{c_{TOT}} = 18,260 + 5,660 = 23,420 \text{ psi}$$

Figure 29. Continued.

$P_{CAP} = 237{,}921/5.833 = 40{,}789$ lb

$V_{UPR} + V_{LWR} = 17{,}276 - 10{,}850 = 6{,}426$ lb

$$V_{LWR} = \left(\frac{.71307}{3.66322 + .71307}\right) \times 6{,}427 = 1{,}047 \text{ lb}$$

$V_{UPR} = 6{,}426 - 1{,}047 = 5{,}379$ lb

$P_{CAP} = 237{,}921/5.833 = 40{,}790$ lb

<u>Fixed End Moment at Edge of Cutout</u>

1) Due to Tine Load:

$$M' = \frac{1}{24}\ \frac{W}{L}\ (C^2 - 3L^2)$$

$C = 8$ in.

$L = 13$ in.

$W = 28{,}125$ lb

$$M' = \frac{1}{24} \times \frac{28{,}125}{13}\ (8^2 - 3 \times 13^2) = -39{,}934 \text{ in.-lb}$$

2) Due to Beam Shear:

$M' = (V_{UPR}/2) \times 6.5 = 5{,}379 \times 6.5/2 = 17{,}482$ in.-lb

$M_{TOT} = -39{,}934 - 17{,}482 = -57{,}416$ in.-lb

-or-

$M_{TOT} = -39{,}934 + 17{,}482 = -22{,}452$ in.-lb

$$\left.\begin{array}{l} F_{tu} = 27{,}000 \text{ psi} \\ F_{su} = 15{,}000 \text{ psi} \end{array}\right\}$$

WELD ALLOWABLES
OF 6061-T6

$$R_c = \frac{23{,}920}{27{,}000} = .886$$

$$R_s = \frac{2{,}325}{15{,}000} = .155$$

$$M.S. = \frac{1}{[R_c^{\ 2} + R_s^{\ 2}]^{1/2}} - 1 = \frac{1}{.886 + .155} - 1 = +.11$$

Lower Cap

Moment at Edge of Cutout

$$M = (V_{LWR}/2) \times 6.5 = 1{,}047 \times 6.5/2 = 3{,}403 \text{ in.-lb}$$

$$f_b = \frac{Mc}{I} = \frac{3{,}403 \times .6414}{.71307} = 3{,}060 \text{ psi}$$

$$f_t = \frac{P}{A} = \frac{40{,}790}{4.4151} = 9{,}239 \text{ psi}$$

$$f_{t_{TOT}} = 9{,}239 + 3{,}060 = 12{,}299 \text{ psi}$$

$$f_s = \frac{V}{A} = \frac{1{,}047}{4.4151} = 237 \text{ psi}$$

$$M.S. = \frac{27{,}000}{12{,}299} - 1 = +1.2$$

Column Analysis

Column analysis is performed on all braces. The critical column load is taken from the Summary - Superstructure Limit Brace Loads. For all brace members whose L'/ρ is greater than $\pi\ [2E/F_{cc}]^{1/2}$, Eulers Column formula is used; for values greater, Johnsons's column formula is used. The material for all members is 6061-T6 drawn tubing.

F_{cc} is the same as $F_{cy} = 34{,}000$ psi

$E_c = 10.1 \times 10^6$ psi

$$\pi\,[2E/F_{cc}]^{1/2} = \pi\,[2 \times 10.1 \times 10^6/34{,}000]^{1/2} = \underline{76.57}$$

Eulers Formula

$$F_{CR} = \frac{\pi^2 E}{(L'/\rho)^2}$$

Johnsons Formula

$$F_{CR} = F_{cc} - \frac{F_{cc}^{\,2}(L'/\rho)^2}{4\pi^2 E}$$

Margin of Safety

The loads presented in the Summary - Superstructure Limit Brace Loads are multiplied by 1.5 as an ultimate load factor. The margin of safety is calculated by

$$M.S. = \frac{\text{Allow Load}}{\text{Actual Load (Ultimate)}} - 1$$

TABLE 18

SUMMARY OF BRACE STRUCTURE COLUMN ANALYSIS FOR SUPERSTRUCTURE

MEMBER	LENGTH (IN.)	OUTSIDE DIAMETER (IN.)	WALL THICKNESS (IN.)	L'/ρ	AREA (IN^2)	F_{CR} (PSI)	ALLOW LOAD (LB)	ACTUAL LOAD (LB)	M.S.
Corner Stanchion 78001204	88.59	5.0	.25	48.09(1)	3.731	27296	101830	101250	0.0
Side Diagonal 78001207-3	97.92	5.0	.25	58.23	3.731	24171	90172	32549	1.8
End Diagonal 78001207-5	119.64	5.0	.25	71.14	3.731	19326	72100	40074	.8
Top Diagonal 78001207-7	129.19	5.0	.25	76.82	3.731	16891	63015	42636	.5
Center Post 78001207-1	84.49	5.0	.25	50.24	3.731	26682	99541	11913	7.4
Top End 78001209	79.29	5.0	.25	47.15	3.731	27555	102798	27000	2.8
Top Side 10' 78001203	117.66	5.0	.25	69.96	3.731	19808	73897	46124	.6
Top Side 20' 78001202	(Hor) 238.38 (Vert) 119.19	6.5	.25	76.22(2)	4.909	17157	84219	63658	.3

(1) Use C = 1.2 for socket at upper end of tube for $L' = L/\sqrt{C}$

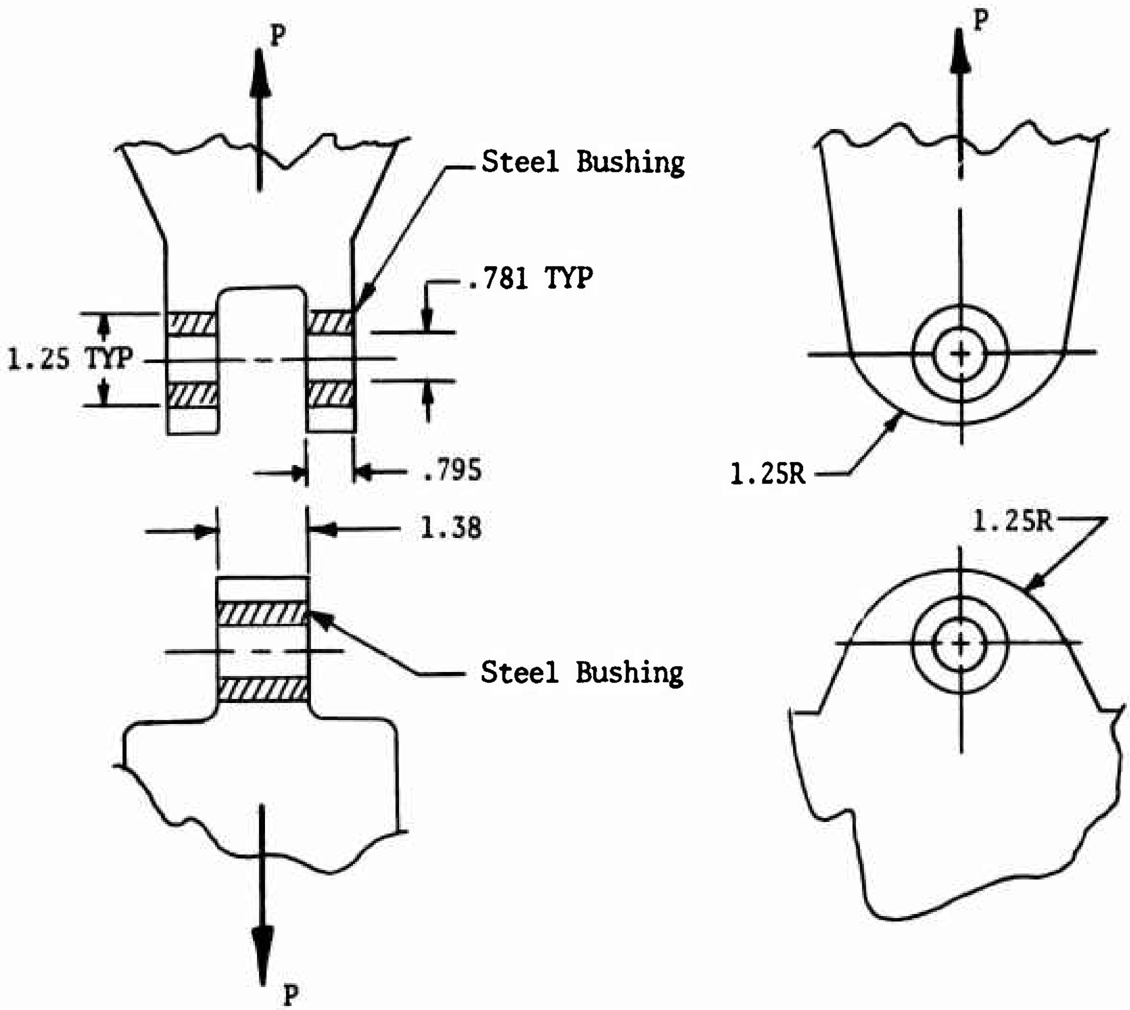
(2) Use C = 2.0 for tube welded to end castings.

Typical Lug and Pin Analysis

All tube end clevis fittings are similar.

Critical Compression: 101,250 lb ult. on corner stanchion for six-high stacking.

Critical Tension: 42,636 lb ult. on top diagonal for .6 G sidesway.



Lug Material: A356-T6 Aluminum Casting

Shear Out-Bearing Analysis

$e/D = 1.25/1.25 = 1.0$

$D/t = 1.25/.795 = 1.6$

$K_{bru} = .85$

$P_{bru} = K_{bru}\ A_{br}\ F_{tu} = .85 \times (1.25 \times 1.38) \times 38{,}000$

$= 55{,}718$ lb ult.

$$M.S. = \frac{55{,}718}{42{,}636} - 1 = +.31$$

Compression Bearing

$$f_{bru} = \frac{101{,}250}{1.25 \times 1.38} = 58{,}696 \text{ psi}$$

$F_{bru} = 68{,}000$ psi

$$M.S. = \frac{68{,}000}{58{,}696} - 1 = +.16$$

Pin Shear

Pin Diameter: .75 in. nominal

Material: 4,130 steel 200 ksi H.T.

$$f_s = \frac{101{,}250}{2 \times .75^2\ \pi/4} = 114{,}592 \text{ psi}$$

$F_{su} = 125{,}000$ psi

$$M.S. = \frac{125{,}000}{114{,}592} - 1 = +.09$$

Cone Bearing - Corner Stanchion

Load = 101,250 lb (ult.) due to stacking load.

Area Truncated Cone = π S (R_A + R_B)

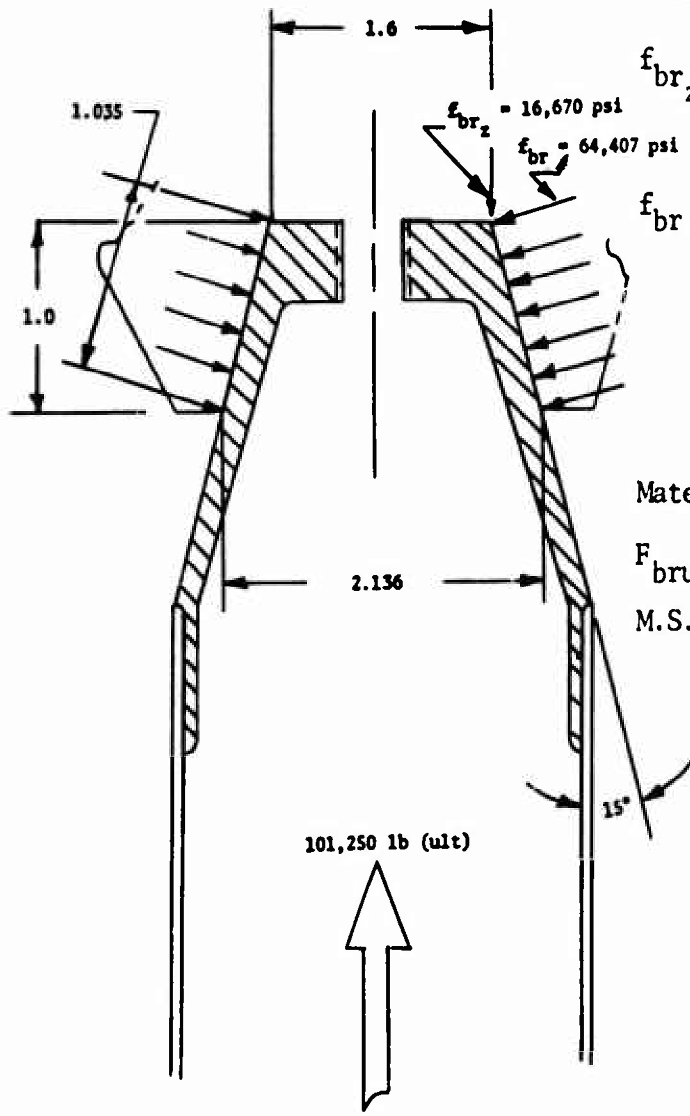
$= \pi \times 1.035\ (.8 + 1.068) = 6.074\ in.^2$

$s = 1/\cos 15° = 1.035$

$R_B = (1.6 + 2 \times \tan 15°)/2$
$= 1.068$

$f_{br_z} = 101,250/6.074$
$= 16,670$ psi

$f_{br} = f_{br_z}/\sin 15° = 64,407$ psi



Material: A356-T6 Casting

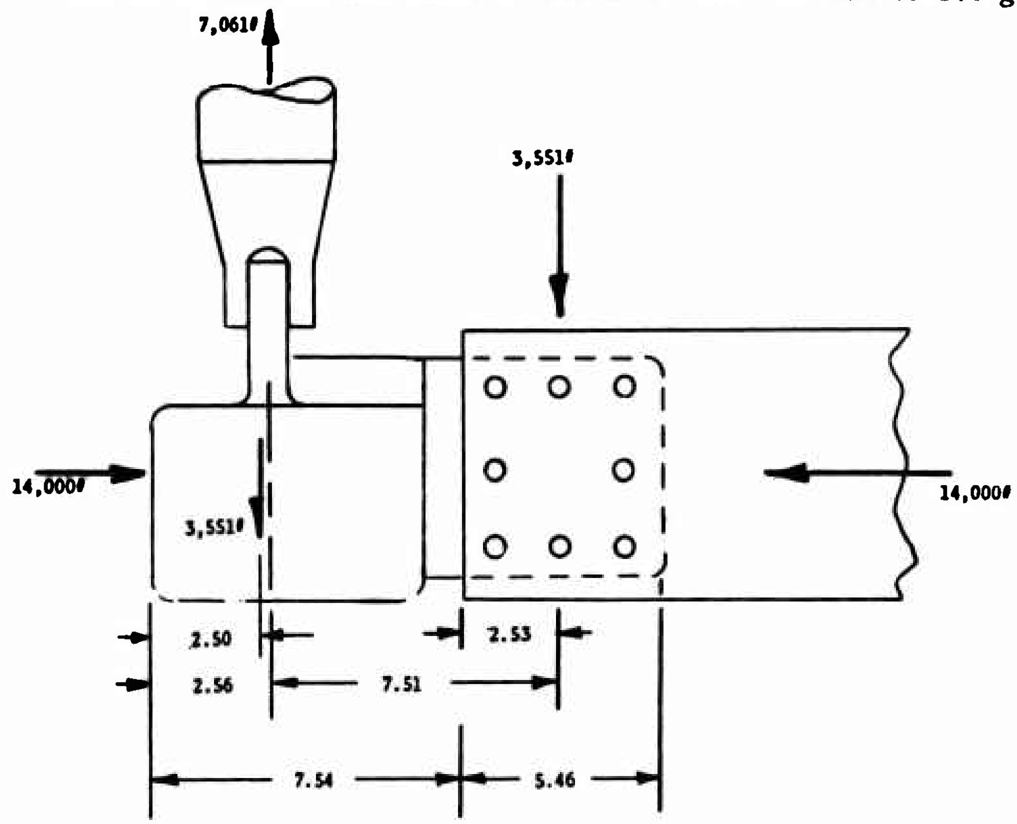
$F_{bru} = 68,000$ psi

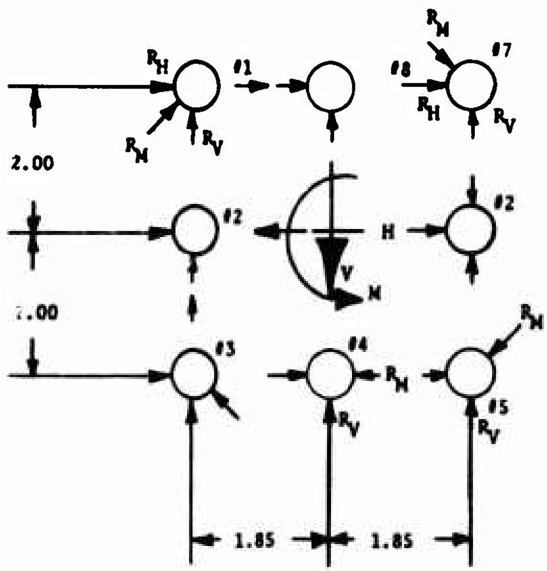
$M.S. = \frac{68,000}{64,470} - 1 = +.06$

JOINT ANALYSIS

Side Beam to Corner Casting

The 10-ft Gondola has the critical load condition due to 3.0 g lift.





$V = 3{,}551$ lb
$M = 3{,}551 \times 7.51 = 26{,}668$ in.-lb
$H = 14{,}000$ lb

$$I = \Sigma R^2 = 4 \times 2.724^2 + 2 \times 2.0^2 + 2 \times 1.85^2 = 44.535$$

$$R_{M_1} = \frac{26668 \times 2.724}{44.535} = 1{,}631 \text{ lb}$$

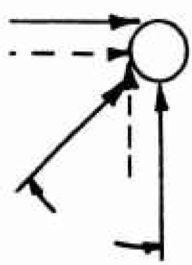
$$R_{M_2} = \frac{26668 \times 1.85}{44.535} = 1{,}108 \text{ lb}$$

$$R_{M_8} = \frac{26668 \times 2.0}{44.535} = 1{,}198 \text{ lb}$$

$R_V = 3{,}551/8 = 444$ lb

$R_H = 14{,}000/8 = 1{,}750$ lb

Critical Attachments are #1 and #3



Total Attachment Load is
(1,750 + 1,197) $\overset{\rightarrow}{+}$ (1,108 + 444) = 3,331 lb (limit)

Attachment

HL2075-12AW, which is a 3/8-in.-diameter HI-LOK bolt 160-180 ksi heat treatment.

Shear

Single Shear Allowable = 10,490 lb

$$\text{M.S.} = \frac{10{,}490}{1.15^* \times 1.5^* \times 3{,}331} = +.82$$

Bearing

F_{bru} (A356) = 53,000 psi

F_{bru} (6061-T6) = 69,000 psi

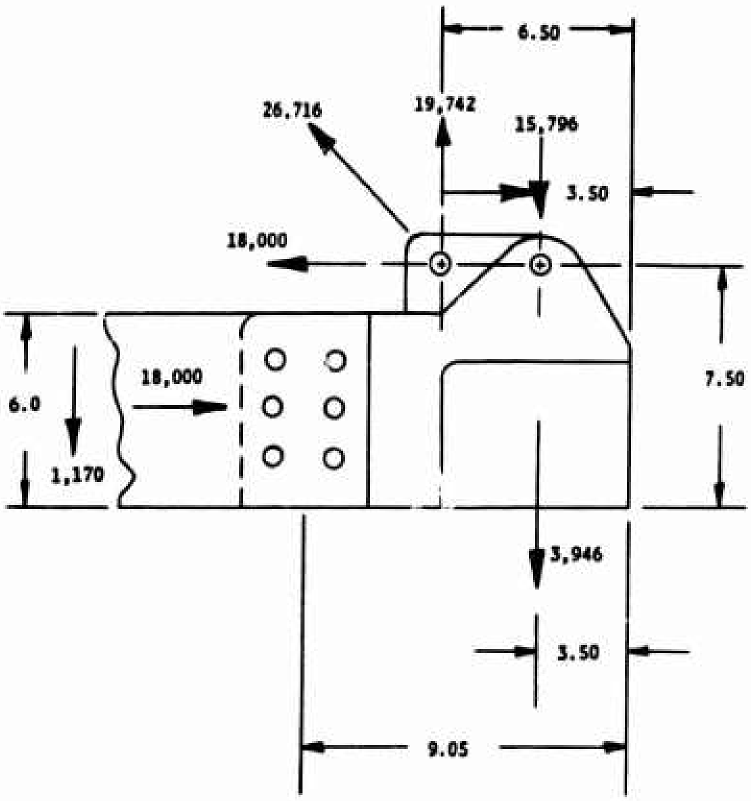
Bearing Allowable = 53,000 x .38 x .375 = 7,552 lb
-or-
= 69,000 x .23 x .375 = 5,951 lb

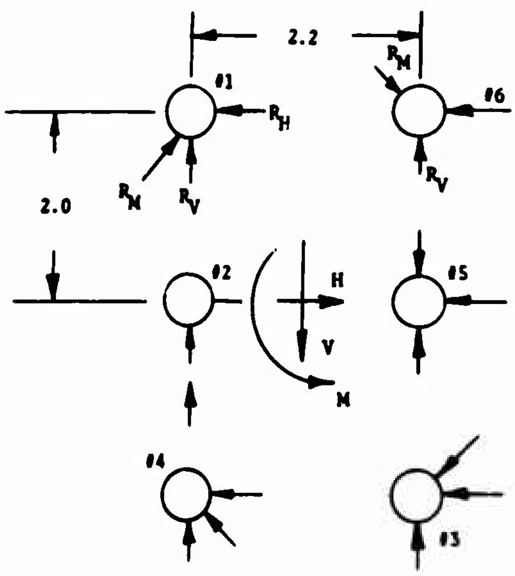
$$\text{M.S.} = \frac{5{,}951}{1.15^* \times 1.5^* \times 3{,}331} - 1 = +.04$$

* 1.15 is a bolt pattern fitting factor and 1.5 is the ultimate load factor.

End Beam to Corner Casting

The 10-ft Gondola is critical for .6 g side sway.





$V = 1,170$ lb

$H = 18,000$ lb

$M = 18,000 \times 4.5 - 19,742 \times 3.0$

$= 21,774$ in.-lb

$I = \Sigma R^2$

$= 4 \times 2.283^2 + 2 \times 1.1^2$

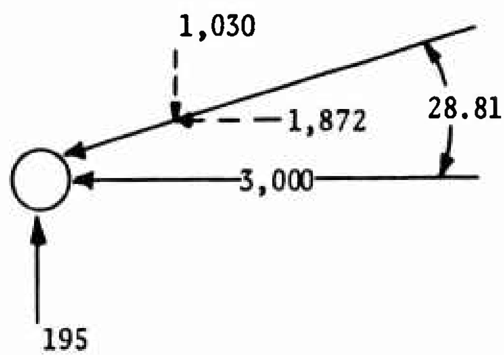
$= 23.26$

Attachment No. 3 is Critical

$R_V = 1{,}170/6 = 195$ lb

$R_H = 18{,}000/6 = 3{,}000$ lb

$$R_M = \frac{21{,}774 \times 2{,}283}{23.26} = 2{,}137 \text{ lb}$$



Total Reaction Attachment No. 1

$R_1 = (3{,}000 + 1{,}872) \overrightarrow{+} (1{,}030 - 195) = 4943$ lb

Attachment

HL2075 - 12AW (3/8 diameter HI-LOK)

Bearing is Critical

$P_{BRU} = 89{,}000 \quad .170 \times .375 = 5{,}674$ lb

$$M.S. = \frac{5{,}674}{4{,}943} - 1 = +.15$$

M54, 5-Ton Truck Loaded on 40-Ft Gondola With M149 2-Wheel Trailer

Weight Distribution - Loaded (Ref MS53087 & 500024)*

	FRONT AXLE (LB)	INNER AXLE (LB)	REAR AXLE (LB)	TOTAL (LB)
Curb Weight	8735	5605	5605	19,945
Pay Load	765	9617	9617	20,000
Tire Loading	9500	15300	15300	40,100
Trailer	-	-	5455	5,455

Tire Loading

Design Loads:

Front Tire = 4750 x 3.0 = 14,250 lb limit (21,375 lb ult.)

Inter &
Rear Tires = 3825 x 3.0 = 11,475 lb limit (17,212 lb ult.)

Trailer Tires = 2728 x 3.0 = 8,184 lb limit (12,275 lb ult.)

Wheel base, truck, 179 inches

Tread -	Front Axle	74 in.
	Inter & Rear Axle	72 in.
	Trailer Axle	67-3/8 in.

Tire Area 9 in. wide-x-10 in. long

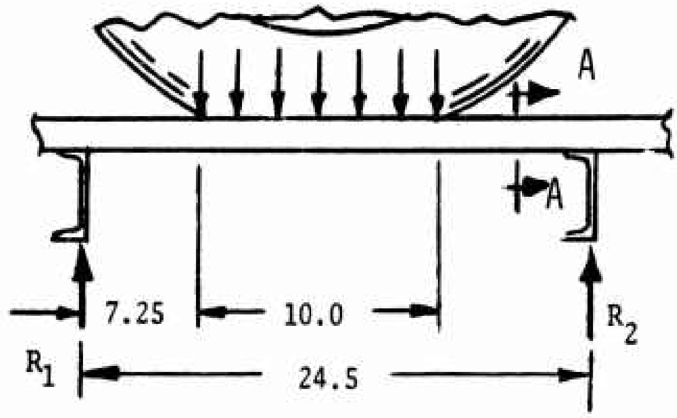
Since trailer axle loads are significantly lower than truck axle loads, they are not analyzed for floor loads.

Check Deck Grating

The front tire produces the critical pressure load on the deck. The maximum span between crossbeams is 30 in. but contains intermediate bracing. Therefore, the critical span is 24.5 in.

* Heaviest Vehicle in Table 2

21375 lb (ultimate)

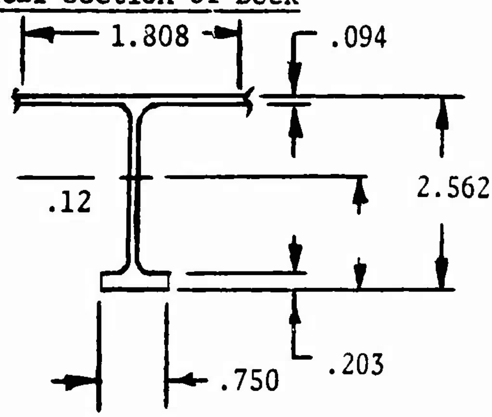


Assume a simply supported beam.

$R_1 = R_2 = 21,375/2 = 10,688$ lb

M_{MAX} = 96,855 in. lb for 9-in. plank
= 10,762 in.-lb/in. of deck

Typical Section of Deck



SECTION AA

Section Properties:

Area = .5944 $in.^2$
$\bar{Y}$ = 1.3574 in.
I = .5854 $in.^4$

Material:
6061-T6 Extrusion
Wt. = 5.31 lb/ft for 9-in. plank.

Bending Analysis

f_b = 10762 x 1.3574/.5854 = 24954 psi tension in lower flange, ultimate stress.

F_{tu} = 40,000 psi

$$M.S. = \frac{40,000}{24,954} - 1 = .60$$

Web Shear Analysis

$F_{s_{max}} = VQ/It$

Where $V = R = 10688$ lb for 9-in. plank

$V = 2{,}147$ lb for 1,808 in. of deck

$Q = .203 \times .75 \times 1.2559 + .12 \times 1.1544 \times .5772$

$= .2712 \text{ in.}^4$

$F_{s_{max}} = 2147 \times .2712/(.5854 \times .12) = 8{,}289$ psi

$F_{s_{cr}}$ = (critical shear buckling stress) = $K_s E(t/b)^2$

$F_{s_{cr}} = 5 \times 10.1 \times 10^6 \, (.12/2.265)^2 = 141{,}748$ psi, obviously not critical

$F_{su} = 29{,}000$ psi

$$\text{M.S.} = \frac{29{,}000}{8{,}289} - 1 = +2.5$$

Check Crossbeam

The crossbeam is critical for rear axle of M54 truck loaded to sit directly on crossbeam. Since the beams are all identical, analysis will cover worst situation. However, the beam is not capable of withstanding the load of a fully loaded truck; therefore, an empty truck will be considered for the crossbeam analysis. For an empty truck, the front axle is critical.

3.0 Helicopter Lift, 40-Ft Gondola

Load: M54 Truck, Loaded	40,100 x 3.0 =	120,300 lb
M149 Trailer, Loaded	5,575 x 3.0 =	16,725
TOTAL	45,675 x 3.0 =	137,025 lb

UPPER STRUCTURE LOADS

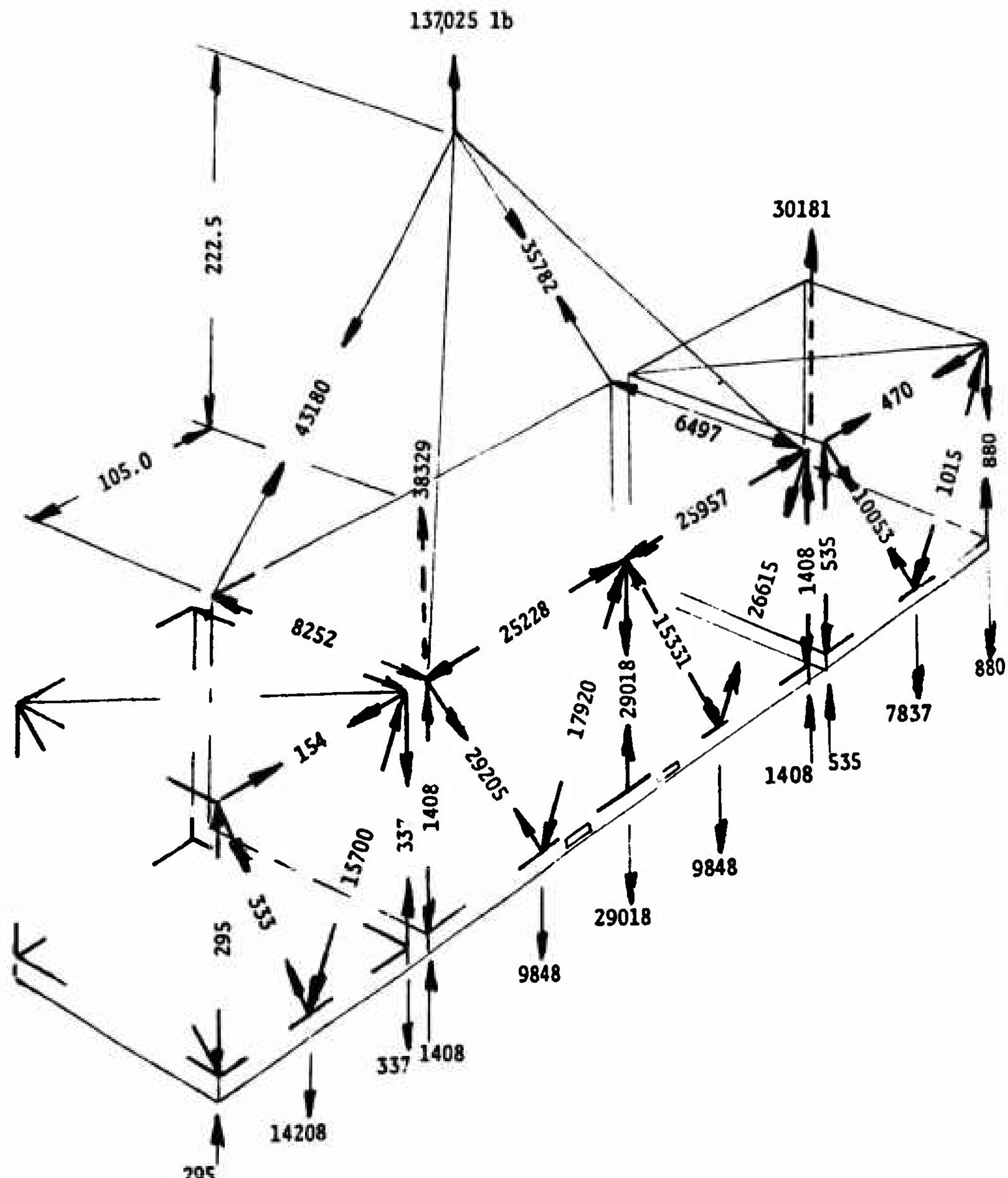


Figure 30. Gondola Loaded With M54 Truck and M149 Trailer.

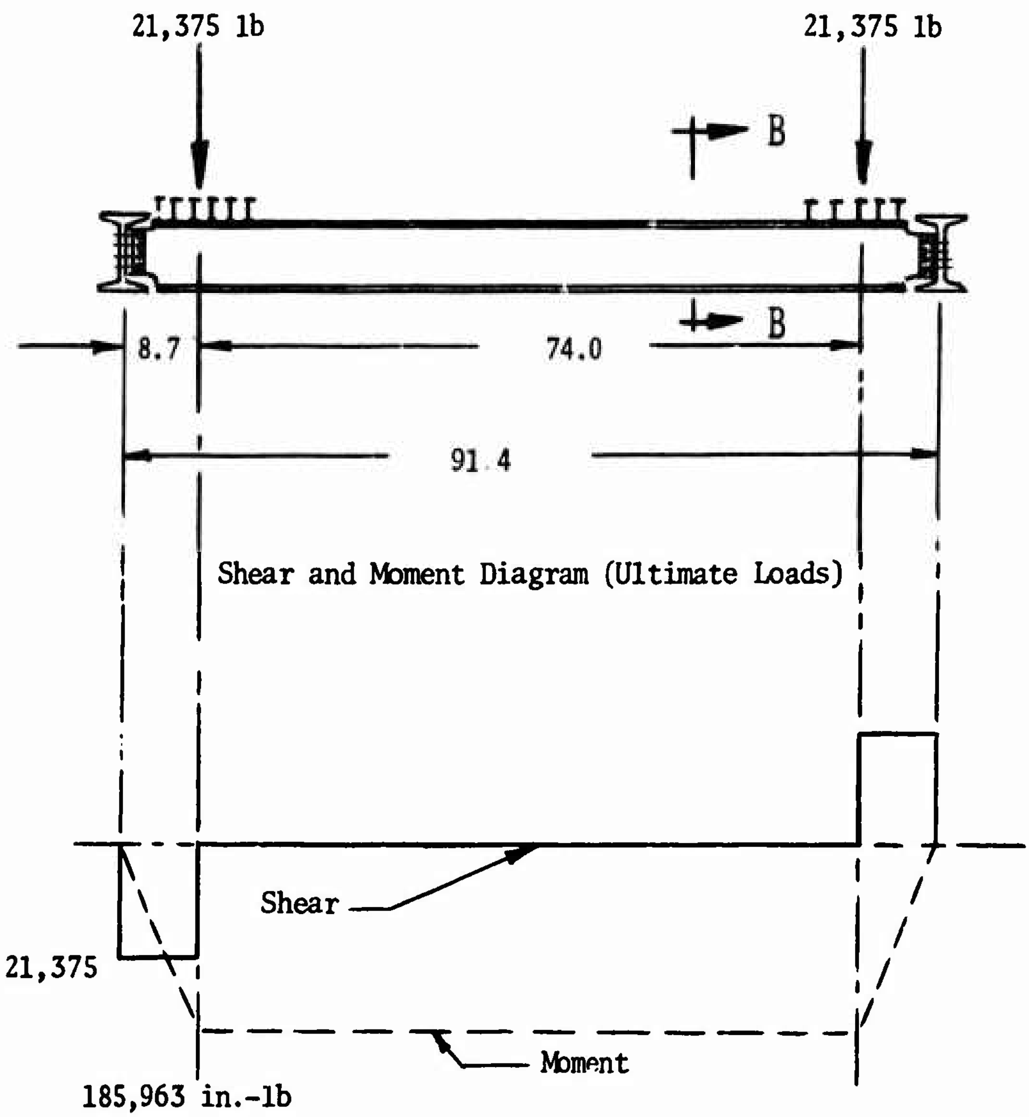
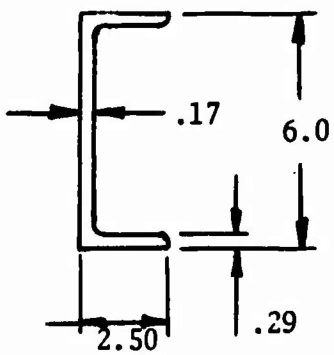


Figure 31. Truck Front Wheel Shear-Moment Distribution on Crossbeams.

Typical Section - Crossbeam



Section Properties:

Area	=	2.3714 $in.^2$
I	=	14.0848 $in.^4$
Z	=	4.6949 $in.^3$

Material:

6061-T6 Extrusion
2.83 lb/ft

Bending Analysis

f_b = 185963/4.6949 = 39609 psi ultimate

The upper flange is in compression but supported by the deck grating every 1.8 inches on center. Therefore, use F_{tu} = 40,000 psi as allowable.

$$M.S. = \frac{40,000}{39,609} - 1 = \underline{\big|\,0.0}$$

Web Shear Analysis

f_s = VQ/It

Where V = 21375 lb

Z = 2.5 x .29 x 2.855 + .17 x 2.71 x 1.355

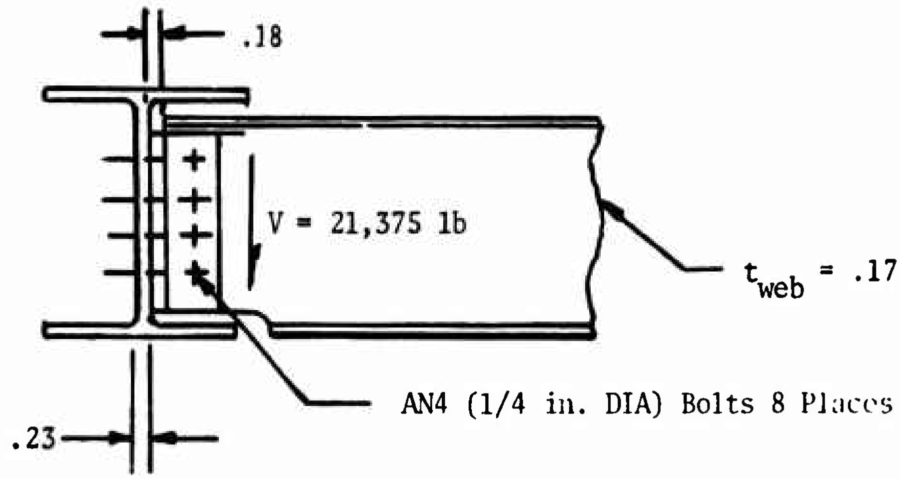
= 2.6941 $in.^4$

f_s = 21375 x 2.6941/(14.0848 x .17) = 24,049 psi ultimate

F_{su} = 29,000 psi

$$M.S. = \frac{29,000}{24,049} - 1 = \underline{\big|\,.20}$$

Crossbeam to Side Beam Attachment



V = 21,375 lb   ultimate (Front Tire Load M54 Truck)

The 1/4-in.-diameter bolts are inadequate by inspection; therefore, the analysis of this joint will consider 3/8-in.-diameter (AN 6) bolts.

Shear Allowable AN 6 Bolt

P_s = 8,280 lb - single shear (Ref MIL-B-6812)

$$M.S. = \frac{8 \times 8280}{21,375} - 1 = \quad 2.10$$

Bearing Allowable

F_{bru} = 89,000 psi

A_{br} = .375 x .17 = .06375 in^2

$P_{bru} = F_{bru} \times A_{br}$ = 89,000 x .06375 = 5,674 lb/bolt

$$M.S. = \frac{8 \times 5674}{21,375} - 1 = \quad 1.12$$

10-Ft Gondola Side Beam

Trailer - Loaded (Ref. MS500024)

Axle Load = 5,455 lb
Wheel Load = 2727.5 x 3.0 = 8,183 lb (Limit Loads)

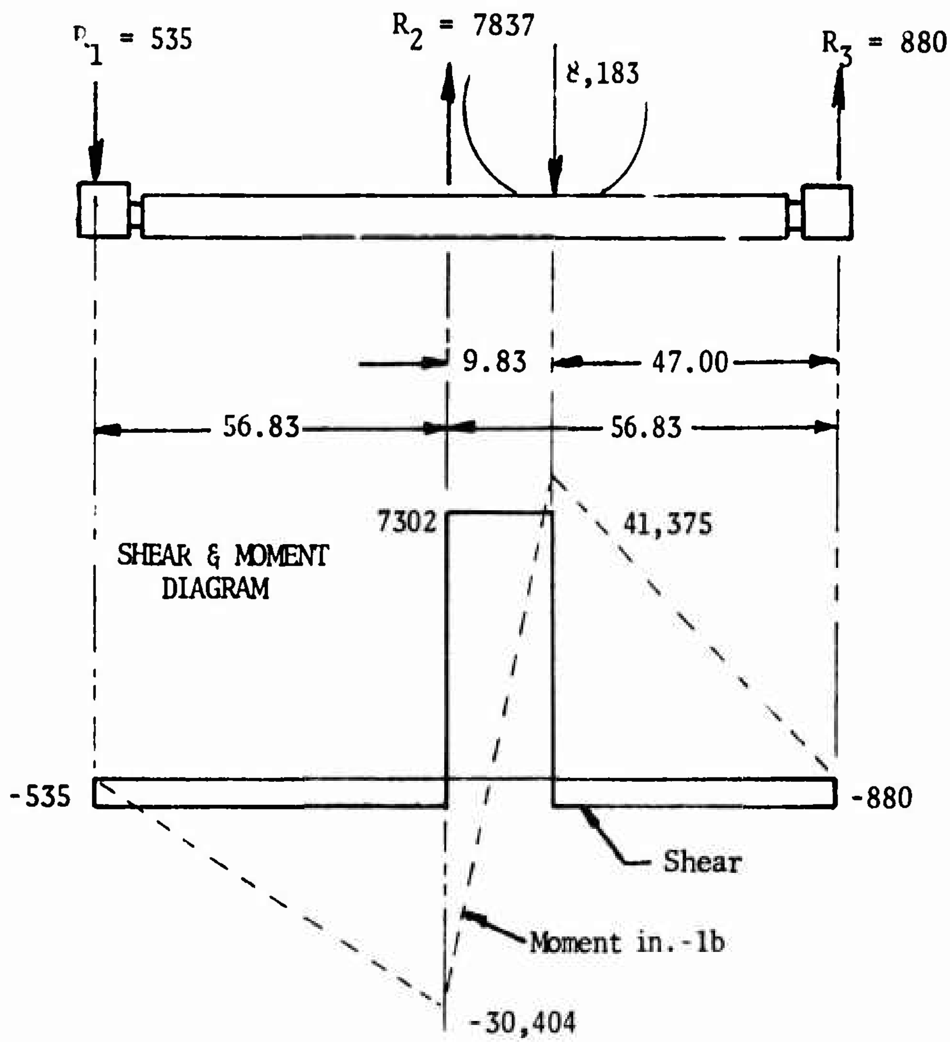


Figure 32. Shear-Moment Distribution on 10-Ft Side Beam for Trailer Axle Load.

M54 Truck Rear Bogie (Loaded) - 20-Ft Gondola

Side Beam Bending Analysis

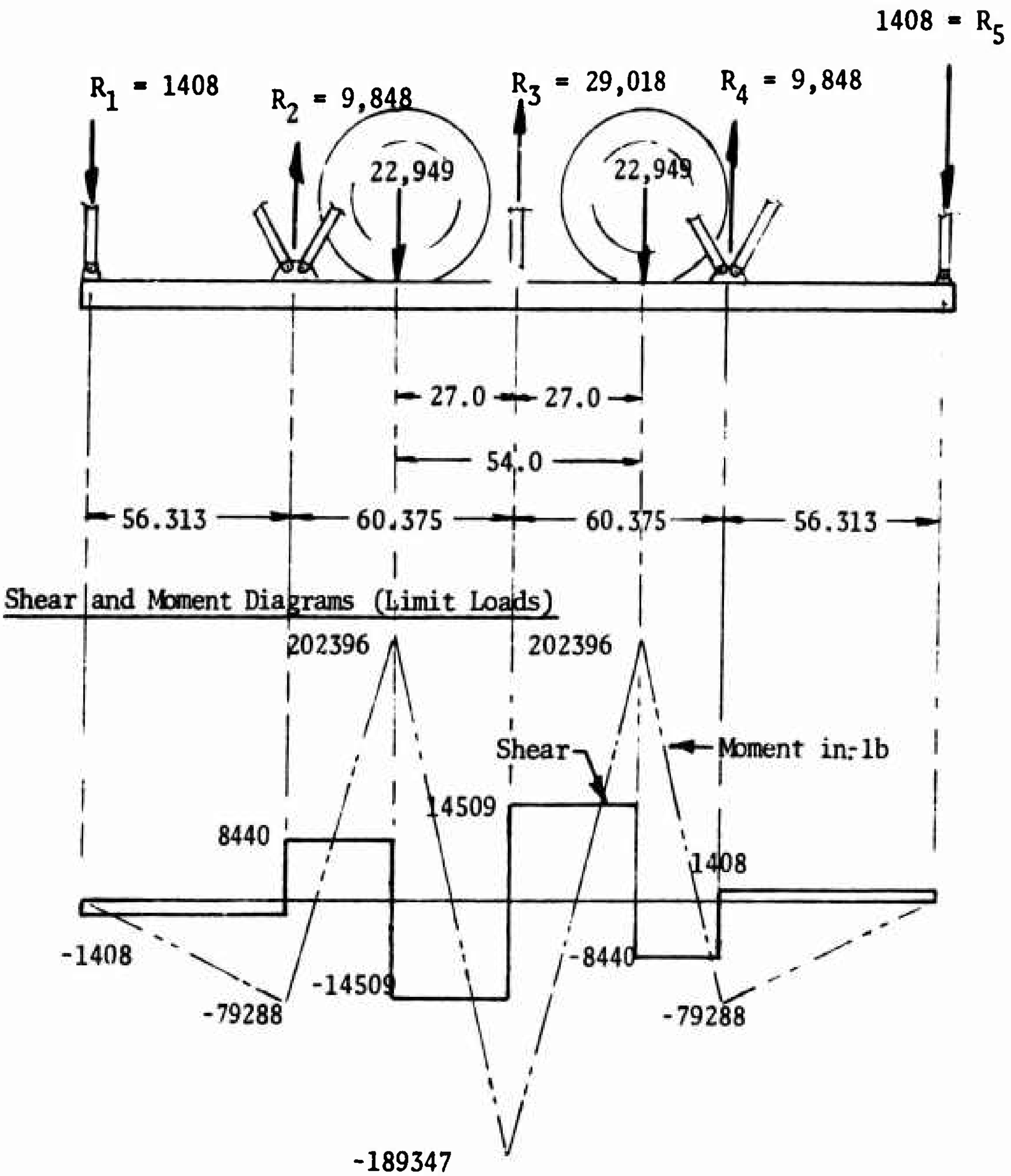


Figure 33. Shear-Moment Distribution on 20-Ft Side Beam for Truck Bogie Wheels.

10-Ft Gondola Sidebeam

M54 Truck Front Wheel (loaded)

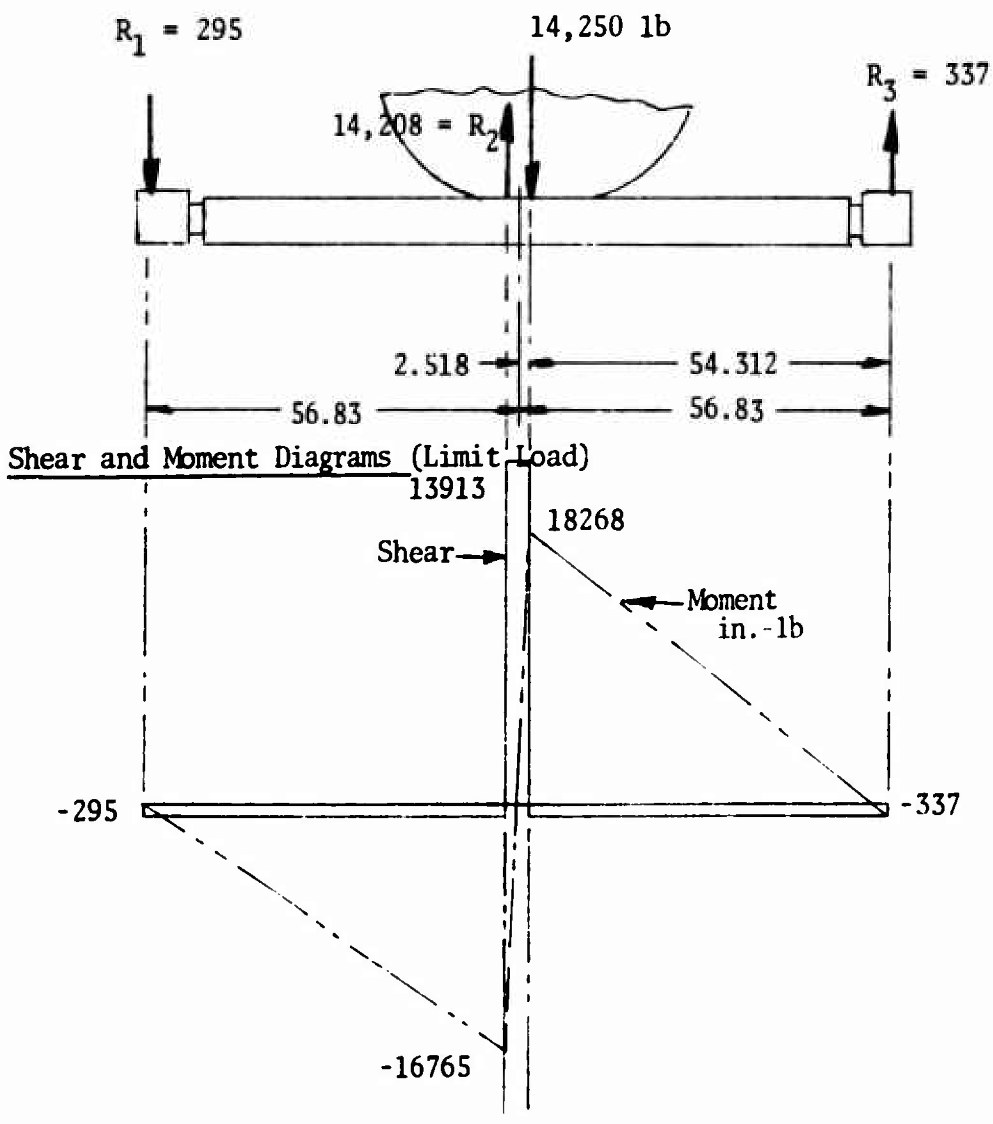


Figure 34. Shear-Moment Distribution on 10-F Side Beam for Truck Front-Wheel Loading.

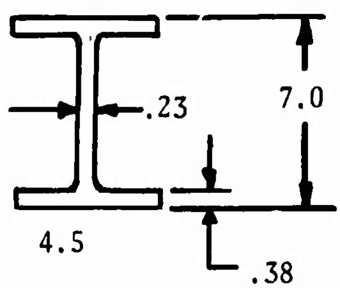
Side Beam Analysis

Maximum Bending = 202,396 in.-lb
Maximum Shear = 14,509 lb

Limit Load

For M54 Truck and M149 Trailer at 45,675 lb combined gross weight.

Side Beam Section Properties



Area = 4.932 in^2
I = 42.89 in^4
Z = 12.25 in^3
Ref. Aluminum Association Standard I-Beams

Bending Analysis

f_b = (202396 x 1.5)/12.25 = 24,783 psi ultimate

F_{tn} = 40,000 psi

M.S. = $\frac{40,000}{24,783}$ -1 = +.61

Web Shear Analysis

F_s = VQ/It

Where: V = 14509 x 1.5 = 21,764 psi ultimate

Q = 4.5 x .38 x 3.31 + .23 x 3.12 x 1.56

= 6.7796

f_s = $21,764 \times 6.7796/(42.89 \times .23) = 14,956$ psi

$F_{s_{cr}}$ = (critical buckling stress) $= K_s E (t/b)^2$

where $K_s = 5.0$

$E = 10.1 \times 10^6$ psi

$F_{s_{cr}}$ = $5 \times 10.1 \times 10^6 (.23/6.24)^2 = 68,600$ psi
Obviously not critical

F_{su} = 29,000 psi

$$M.S. = \frac{29,000}{14,956} - 1 = +.94$$

CONCLUSIONS

1. From the operating characteristics of the three helicopters, two gondola sizes were identified; however, three sizes can be achieved with a coupling of two gondola units.

2. Cargo density and size would suggest 1,000 cu ft capacity for the CH-47/CH-54 and 2,500 cu ft capacity for the HLH, with a payload capacity of 25,000 lb and 60,000 lb respectively. A width of 8 ft would be adequate transport for many vehicles and equipment and break-bulk cargo as required.

3. Stability of the gondola is significantly improved when two or more helicopter attachment points are available. A gondola load attached to a single-point helicopter will fly broadside with significant trail angle and parasitic drag. Attachment points to the load should be above the CG to prevent overturning. Attachment to the helicopter must be accomplished by a sling/pendant/hoist system that will not induce vertical bounce at any load capacity.

4. The gondola should be constructed of rugged structural shapes for the main framing members. Materials must be corrosion resistant and of a thickness such that puncture and abrasion would not render the structure unserviceable. The use of extruded aluminum alloy 6061-T6 should be used as the primary structural material. The use of sheet stock must be avoided.

5. Basically, standard rigging materials can be used in securing cargo. However, existing ground mobility equipment is not compatible with the fully loaded gondolas. Slings should be compatible with the gondolas.

6. The gondola has great potential to be used throughout the system from CONUS through forward resupply; however, it appears that local resupply of advance bases may be better suited to a smaller gondola.

7. The gondola is suited to all modes of transportation if the 8-ft width and 20- or 40-ft length is maintained. However, for fixed-wing transportability, the gondola must be used with the 463L pallet as a slave and would require additional structure for the 9G crash survivability.

8. The gondola is both personnel and cost effective by providing uniform rigging practices and better utilization of manpower. A significant labor saving is experienced when transhipment of cargo is avoided, as can be realized with a gondola when introduced in CONUS deliveries. In helicopter deliveries alone, it is estimated that the gondola cost could be recovered in as few as five missions.

CONCLUSIONS

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9. The design concept selected should provide the load and cubic capacity over a continuous floor that is uninterrupted by support structures. Four lift points are preferred, and they must be above the load CG. A single lift point on smaller gondolas may be acceptable, but it also shall be above the floor.

10. The preferred concept should be so configured as to satisfy the three helicopters. The selected concept presented has this capability.

11. Cost effectiveness can be demonstrated by the capability of the gondola to transport a multiplicity of vehicle or equipment units, thereby reducing the number of trips and attendant helicopter operating costs.

12. Personnel effectiveness is improved by rigging from the same fixed points rather than many different hoisting points for each vehicle or piece of equipment.

13. The reliability of the gondola will demonstrate 95% probability of completing the helicopter mission.

14. Availability of the gondola is based on 24-hour utilization of 2/3 year for 5,840 hours.

15. Maintenance ratio shall not be greater than 0.1, which would allow 58.4 hours annually. This should be more than adequate since it is over 50% of the time required for fabrication.

16. Tare weight savings on a 20-ft gondola is nearly 50% that of an equivalent 20-ft container. Weight savings on a 40-ft gondola is over 20%. In addition, the payload for the 40-ft gondola is approximately 10,000 lb greater in the rotary-wing transport mode.

RECOMMENDATIONS

It is recommended that one unit of the preferred concept be fabricated and tested. The unit would be comprised of two 10-ft sections and a 20-ft mid-section. The unit would be bench tested followed by flight testing through a full spectrum of its utilization cycle.

REFERENCES CITED

1. Berger, S., Heider, F., Lechus, J., Ralston, R., Watson, I., A CRITICAL ANALYSIS OF THE STATE OF THE ART IN CONTAINERIZATION; Control Systems Research In., United States Army Mobility Equipment Research and Development Center, Ft. Belvoir, Virginia, November 1970, AD-877259L

2. Wood, Charles W., Watts, John H., Lucas, Robert M., DESIGN CRITERIA TECHNICAL CHARACTERISTICS, AND DESIGN CONCEPTS FOR AN AIR TRANSPORTABLE CONTAINER, Aurthus D. Little, In.,; USAAML Technical Report 65-36, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, June 1965, AD-619158

3. Brizinski, S. J., Karras, G. R., CRITERIAL FOR EXTERNALLY SUSPENDED HELICOPTER LOADS; USAAVLABS Technical Report 71-61, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virgi-nia, November 1971

4. Huebner, Walter E., DESIGN GUIDE FOR LOAD SUSPENSION POINTS, SLINGS, AND AIRCRAFT HARD POINTS; USAAMRDL Technical Report 72-36, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1972, AD-747814

5. Lehmann, Maurice John William; Captain, AERODYNAMIC CHARACTERISTICS OF NON-AERODYNAMIC SHAPES, Air Force Institute of Technology, Wright-Patterson Air Force Base, June 1968

6. Gabel, Richard, Wilson, Gregory; TEST APPROACHES TO EXTERNAL SLING LOAD INSTABILITIES, Vertol Division, The Boeing Co.

7. Bradley, J., Toms, G., BRIDGE EMPLACEMENT TRIALS-PHASE II USING CH-47A AND CH-54A HELICOPTERS; Aeroplane and Armament Experimental Establishment, Boscombe Down, United Kingdom

8. Krolikiewicz, DESIGN, DEVELOPMENT, FABRICATION, AND TESTING OF SMALL AND LARGE LOAD-BEARING PALLETS FOR THE CH-54 "FLYING CRANE" HELICOPTER; Brooks & Perkins Inc., USAAVLABS Technical Report 68-71, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, October 1968, AD-680283

9. Military Handbook Strength of Metal Aircraft Elements, Department of Defense, MIL-HDBK-5, 1 September 1971

10. Military Handbook Plastics for Aerospace Vehicles, Department of Defense, MIL-HDBK-17A, January 1971

11. FM 101-10-1 STAFF OFFICERS FIELD MANUAL, July 1971

12. TM 55-450-8, Air Transport of Supplies and Equipment, External Transport Procedures, December 1968

13. TM-55-450-11, Air Transport of Supplies and Equipment Helicopter External Loads, Rigged with Air Delivery Equipment, June 1968

14. TM 55-450-12, Air Transport of Supplies and Equipment Helicopter External Loads for Sling, Nylon Chain, Multiple Leg (15,000 LB CAP) June 1969

15. TM 55-450-19, Air Transport of Supplies and Equipment, Helicopter External Lift Rigging Materials Techniques and Procedures

16. TM 55-1520-217-10/2 Operators Manual CH-54A Helicopter, February 1969

17. TM 55-1520-227-10 Operators Manual CH-47B/C Helicopters, December 1961

18. Vichness, J. A., Deacon, J.A., CARGO COMPARTMENT OPTIMIZATION STUDY, ARMY TRANSPORT AIRCRAFT; USAAVLABS Technical Report 66-79, U. S. Army Aviation Material Laboratories, Fort Eustis, Virginia.

19. Finlay, Patrick, JANES FREIGHT CONTAINERS, 1972-1973, Fifth Edition

20. Hone, Horace T., Huebner, Walter E., DEVELOPMENT OF CARGO SLINGS WITH NON-DESTRUCTIVE CHECKOUT SYSTEMS; Interim Technica Report, Sikorsky Aircraft Division of United Aircraft, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, DAAJ02-72-C-0008

21. Lancashire, T., et al INVESTIGATION OF THE MECHANICS OF CARGO HANDLING BY AERIAL CRANE-TYPE AIRCRAFT; Vertol Division, The Boeing Co., USAAVLABS Technical Report 66-63, U. S. Army Aviation Material

22. Burroughs, Lester R., Ralsten, Harold E., DESIGN STUDY OF HEAVY LIFT HELICOPTER EXTERNAL LOAD HANDLING SYSTEMS, Sikorsky Aircraft, Division of United Aircraft Corporation, USAAVLABS, Technical Report 67-46, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, November 1967, AD-828283

23. FM 55-70, Army Transportation Container Operations, the U. S. Army Transportation School, July 1973

24. TB 55-46-2, Standard Characteristics (Dimensions, Weight and Cube) For Transportability of Military Vehicles and Equipment.

25. American National Standard MH5.1-1970, Eleventh Draft, June 1, 1970

26. MIL-A-8142C (USAF) Air Transportability Requirements, General Specification For, 14 August 1969

APPENDIX A
OTHER GONDOLA CONCEPT ANALYSES

20-Ft FOLDING GONDOLA (20,000-lb CAP)

Summary

The primary structural members will be identical to the nonfolding 20-footer.

The hinge on the bottom of the floor crossbeam must be bolted in order to preserve the unwelded condition of the 6061-T6 material. The flange width of this crossbeam is 1.920 in., and no more the .500 in. of this may be removed, at any one cross section, for bolt holes.

Alternatively, if the hinge were welded, the crossbeam must be increased to 7-in.-x-4.23-lb or 8-in.-x-4.25-lb channels, which increases the weight by 102.2 lb.

Miscellaneous weight allowance must be greater for the folding gondola due to the additional hardware required.

NET	974.5 lb (bolted hinge)	1076.7 lb (welded hinge)
MISCELLANEOUS	300	300
TOTAL	1274.5 lb	1376.7 lb

8-Ft FOLDING GONDOLA (8,000-lb CAP)

Loading

LD = $8{,}000\ (3)/(8)^2 = 375\ \text{lb/ft}^2$

GIA 1-1/2 in. provides 390 lb/ft^2 @ 4-ft-0 spacing

WT = $2.69(8)^2 = 172.2$ lb

4-Ft Beam

LD = $375(8) = 3{,}000$ lb

M = $2(3{,}000)\ 4\ (12)/3 = 96{,}000$ in.-lb

S = $96{,}000(1.15)/15{,}000 = 7.36\ \text{in.}^3$

Select 6 I 4.30

WT = $4.30\ (4)(4) = 68.8$ lb

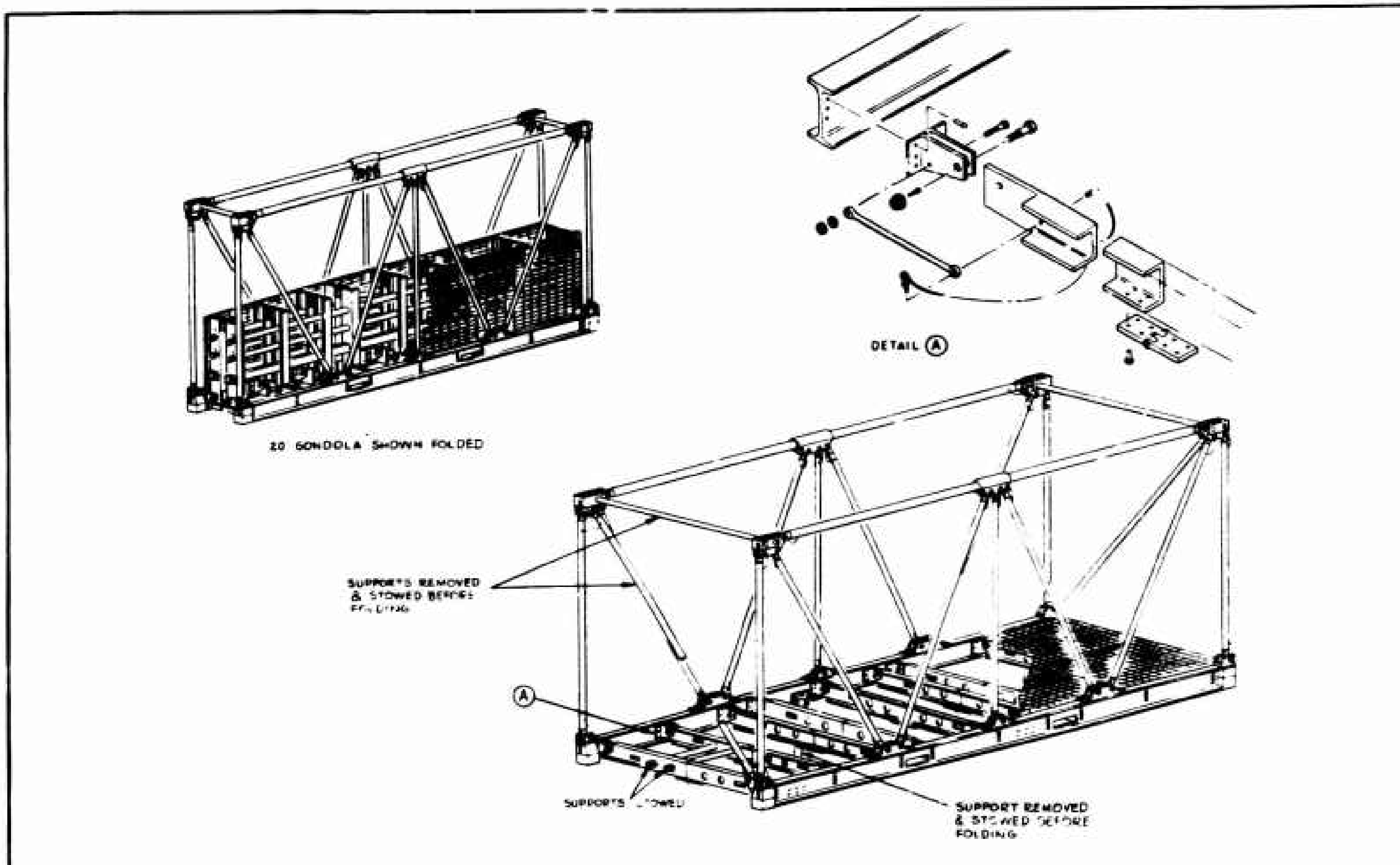

Figure A-1. Folding Gondola - 20-Ft.

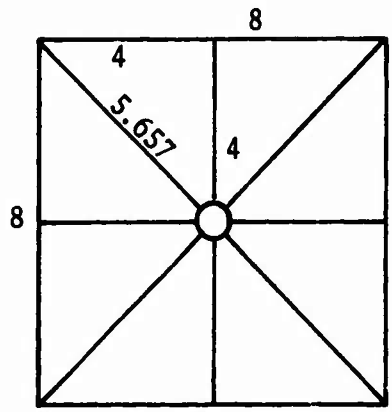

Figure A-2. Folding Base, 8-x-8-Ft.

5.657-Ft Beam

LD = 375(8) = 3,000 lb

M = 2(3,000) (5.657) 12/3 = 135.768 in.-lb

S = 135,768 (1.15)/15,000 = 10.409 in.^{3}

Select 7 I 5.27

WT = 5.27 (4)(5.657) = 119.2 lb

Post

LD = 375 (64) = 24,000 lb

A_R = 24,000 (1.15)/15,000 = 1.84 in.^{2}

Select 4-1/2 - 3/16

WT = 2.54 (8) = 20.3 lb

Summary

NET WT	380.5 lb
MISCELLANEOUS	50
TOTAL	430.5 lb

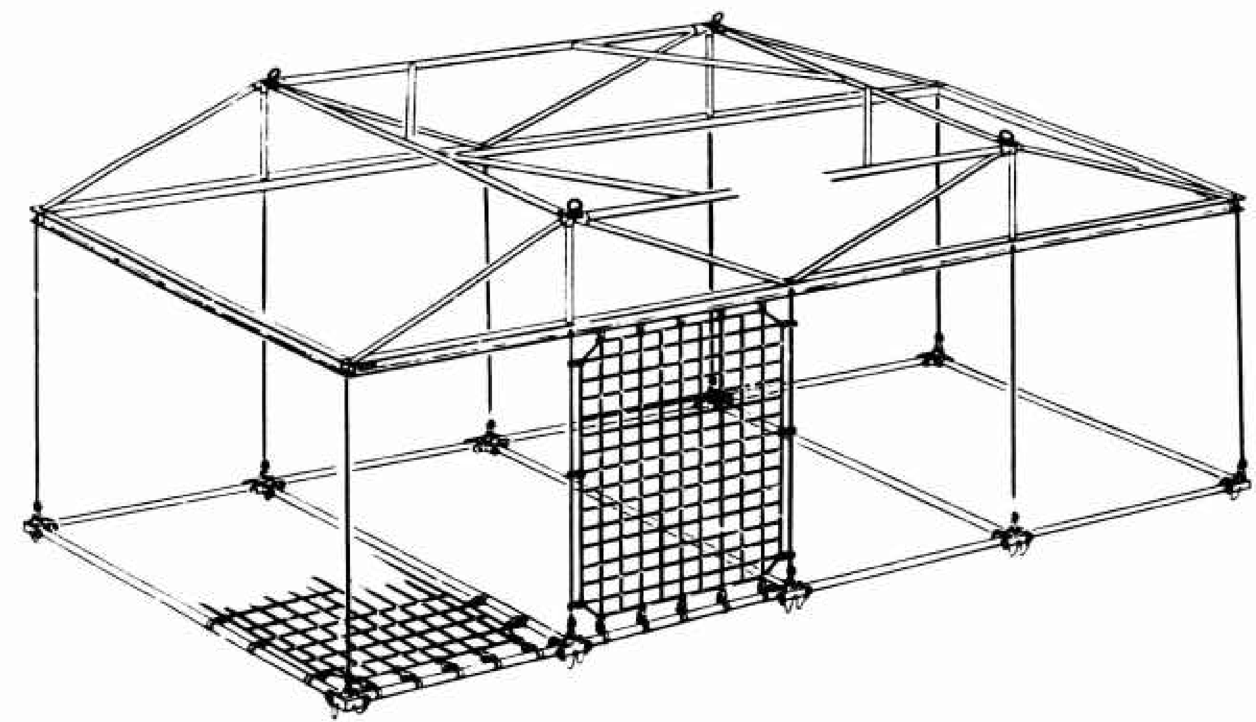

Figure A-3. Soft Base Gondola, 8-x-20-Ft.

Soft Base Gondola

This concept was generated to minimize the deficiencies inherent in a cargo net while taking advantage of lightweight nets and high-density stowage. The concept is indeed lightweight but has limited utilization beyond the helicopter transportation mode. This concept was analyzed for structural sizing, and the results are presented in Table A-1.

TABLE A-1
LOADS AND MEMBER SIZING
SOFT BASE GONDOLA

MEMBER	EXTRUDED SHAPE	SIZE		PRINCIPAL LOAD	
		MAX. DIM. (in.)	WEIGHT (lb/ft)	LOAD	TYPE
Lower Cross	Tube	6-1/2	4.372	158,520 in/lb	Mom. Hor.
Lower Longitudinal	Tube	6-1/2	4.372	157,740 in/lb	Mom. Hor.
Vertical	Chain	2.3	2.76	34,500 lb	Tension
Upper Cross	Channel	4.0	1.85	ϕ	(Stab.)
Upper Longitudinal	Tube	1-3/4	.75	8,625 lb	Compres.
Upper Vertical	Tube	1-3/4	.75	8,625 lb	Tension
Nets (Nylon)	N/A	*	N/A	5,000 lb	Tension
Side Diagonal	Tube	2.0	.865	9,660 lb	Tension
Top Braces	Tube	1-3/4	.75	8,625 lb	Compres.

* Equivalent to FSN 3940-641-3410

20-Ft BOEING MATERIALS HANDLING DEVICE (20,000-lb CAP) (REF Pat. 3580,403)

LOADING

LD = 20,000 (3)/8(20) = 375 lb/ft^2

CROSSBEAM (4-Ft Pallet)

LD = 375 (4)(4)/2 = 3,000 lb

M = 3,000 (24) = 72,000 in.-lb

S = 72,000 (1.15)/15,000 = 5.52 in.^{3}

Select 6 I 4.30

WT = 4.30 (4)(20) = 344.0 lb

CENTER BEAM

LD = 375 (8)20 = 60,000 lb

M = 60,000 (20)12/8 = 1,800,000 in.-lb

S = 1,800,000 (1.15)/15,000 = 138.00 in.^{3}

There is no standard I-beam large enough.

Estimated weight of beam is 50 (20) = 1,000 lb

POSTS

LD = 30,000 lb

A_R = 30,000 (1.15)/15,000 = 2.30 in.^{2}

Select 4-3/4 - 3/16

WT = 3.161 (8)(2) = 50.6 lb

$A = .125 [\qquad\qquad\qquad] = .575 \text{ in}^2$

$WT = .575 \{(2 \times 120) + (2 \times 96) + (2 \times 154)\} (.1) = 43 \text{ lb}$

Spreader Bar

$LD = 30{,}000 \sin 30° = 15{,}000$

$$\gamma^2 A = \frac{(240)^2\ 15{,}000}{\pi^2\ 10^7}$$

min is 5-1/4 - 3/16

$WT = 3.507 (20) = 70.1 \text{ lb}$

4 x 4 Pallets

WT = 665.7 lb

Cradle

Not included since it does not fly.

Summary

NET WT	2505.4 lb
MISCELLANEOUS	275
TOTAL WT	2780.4 lb

RIGID-BASE PALLET CELL GONDOLA 17-x-7-x-8-Ft (SK78001905)

This concept was designed around a commercially available polystyrene pallet. The support structure is similar to that used for the wood pallet. It was initially conceived to support the pallet about its edge, which proved to be inadequate. However, with more support structure and added weight, the pallet could be utilized. The advantage of the plastic pallet is its stackability and potentially lower life-cycle cost than that of the wooden pallet.

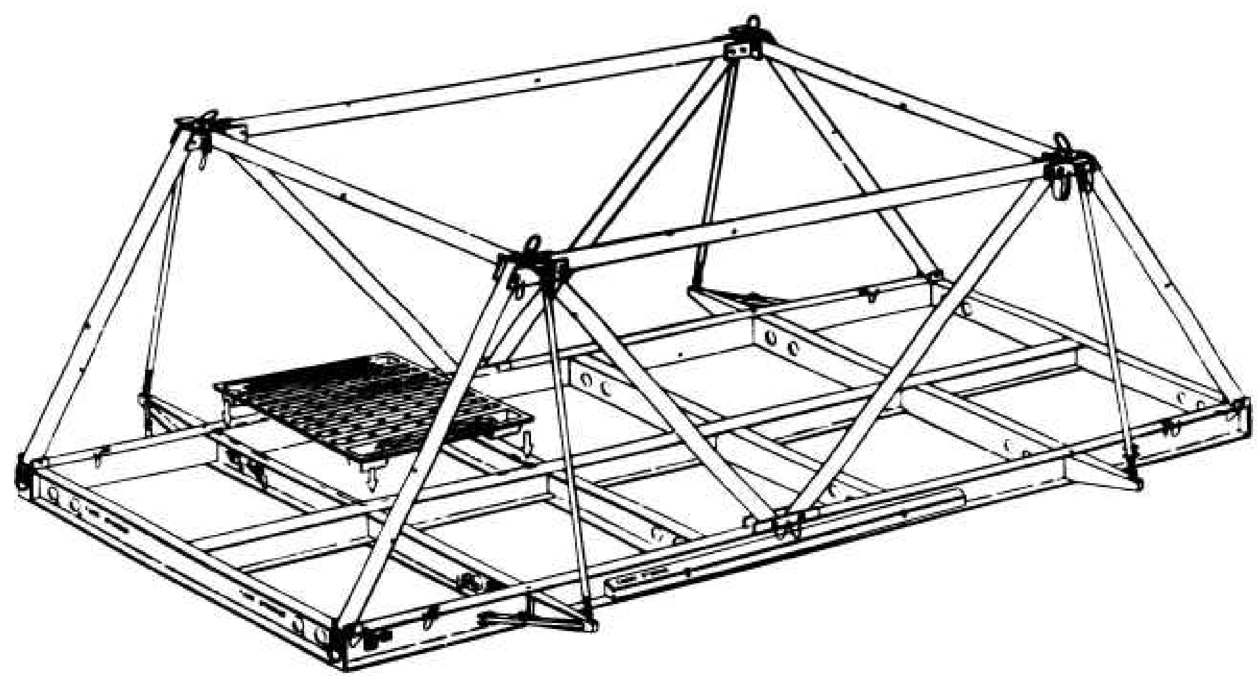

Figure A-4. Rigid-Base Pallet Cell Gondola.

Rigid-Base Pallet Cell Gondola

This concept was initially considered to be used with plastic pallets which would be captured in a rigid-base support structure. The resultant concept proved to be incompatible for standard International Standard Organization container sizing. In addition, the outrigger supports for lateral rigidity proved to be cumbersome and unwieldy. Member loads and attendant sizing are summarized in Table A-2.

TABLE A-2
LOAD AND MEMBER SIZING
RIGID BASE PALLET CELL GONDOLA

MEMBER	EXTRUDED SHAPE	MAX. DIM. (in.)	WEIGHT (lb/ft)	PRINCIPAL LOADS	
				LOAD	TYPE
Lower Longitudinal	I-beam	9.0	7.52	229,565 in/lb	Moment
Cross	Channel	6.0	2.83	90,000 in/lb	Moment
Side End	Tube	2.0	1.95	41,580 lb	Tension
Side Center	Tube	4.25	4.54	72,280 lb	Tension
Side Upper	Tube	4.0	1.85	27,270 lb	Compres.
Outrigger Diagonal	Tube	4.38	2.99	69,669 lb	Ten/Compres.
Outrigger Support	I-beam	7.0	6.9	835,920 in/lb	Moment

APPENDIX B
GONDOLA SIZING METHODOLOGY

SIZING METHODOLOGY FOR SQUARE GONDOLA

Gondola sizing was initiated by considering area density and cubic density as parameters to optimize design geometry. Figure B-1 shows that maximum area density is achieved when the suspended load is a cube. Figure B-2 compares area density for cubic gondolas from 5- to 10-ft with various cubic densities. This analysis demonstrates that cubic gondolas achieve maximum area density between 5 and 7 ft. Figures B-3 through B-7 summarize the principal framing member weights as a percentage of tare weight. The greatest impact occurs for the floor beams; however, the floor grating decreases as cargo density increases. It is noted that the floor beams and grating are most affected by cargo cube density.

Figures B-8 and B-10 compare cubic and oblong gondolas as a function of tare weight. A comparative analysis of a cubic gondola and an oblong one (base length exceeds width) shows that tare weight is increased approximately 1/2% over a cubic gondola for a 20,000-lb capacity. However, a gondola for 50,000 lb becomes more efficient when configured with an 8-x-40-ft floor plan. Figure B-10 demonstrates that as length increases, oblong gondolas become more efficient than cubic configurations.

Following the graphical displays is the analysis of cubic and oblong gondolas at 20,000 lb and 50,000 lb capacities, which are in the range of the helicopter payloads. The analysis shows that the oblong gondola becomes more efficient in transporting loads in excess of 30,000 lb. This sizing analysis demonstrates that tare weight of an oblong gondola is not significantly greater than that for a cubic gondola. Therefore, the gondola may be sized to meet ANSI/ISO geometry consistent with the payload requirements of the helicopter.

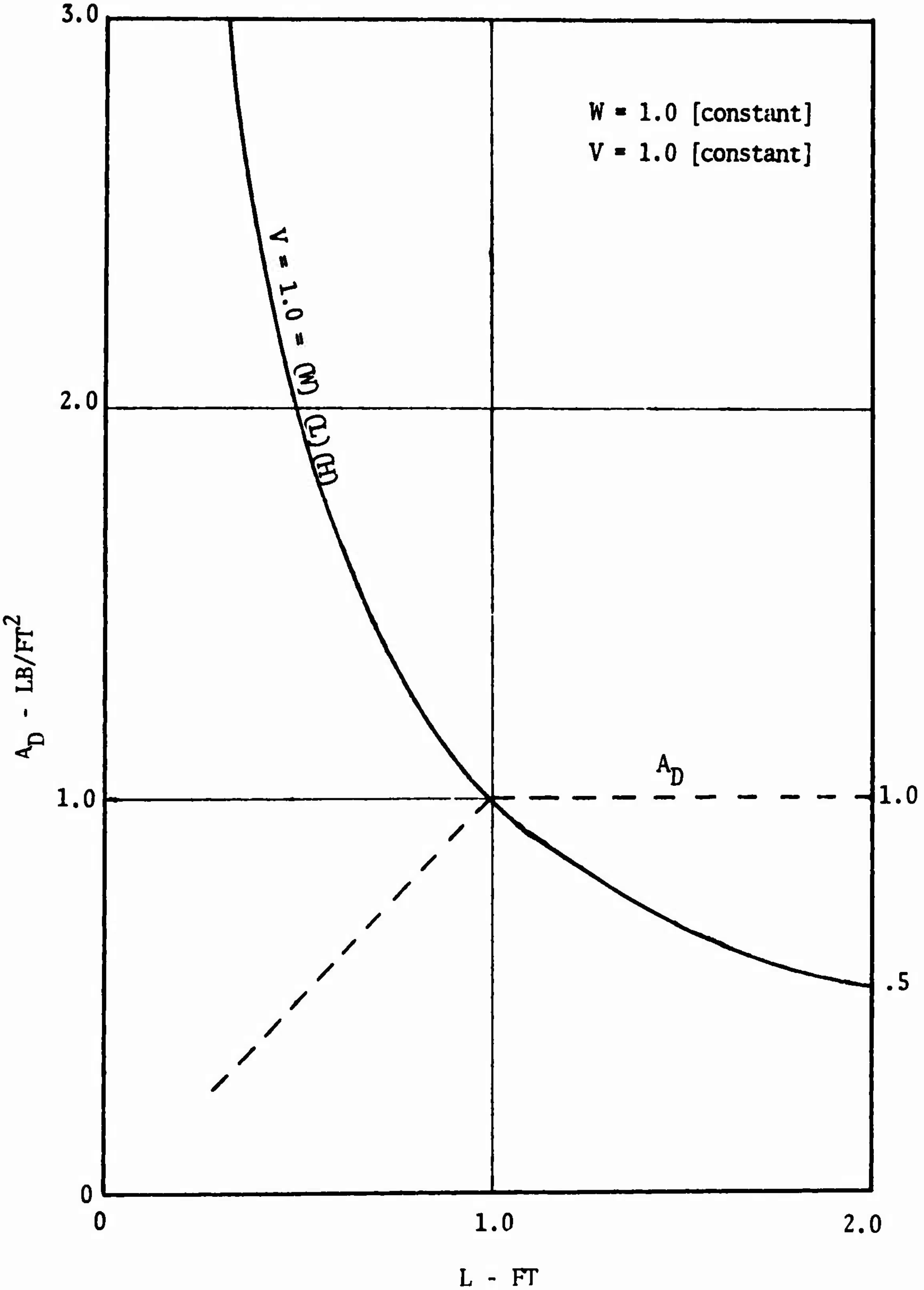

Figure B-1. Area Density Variation.

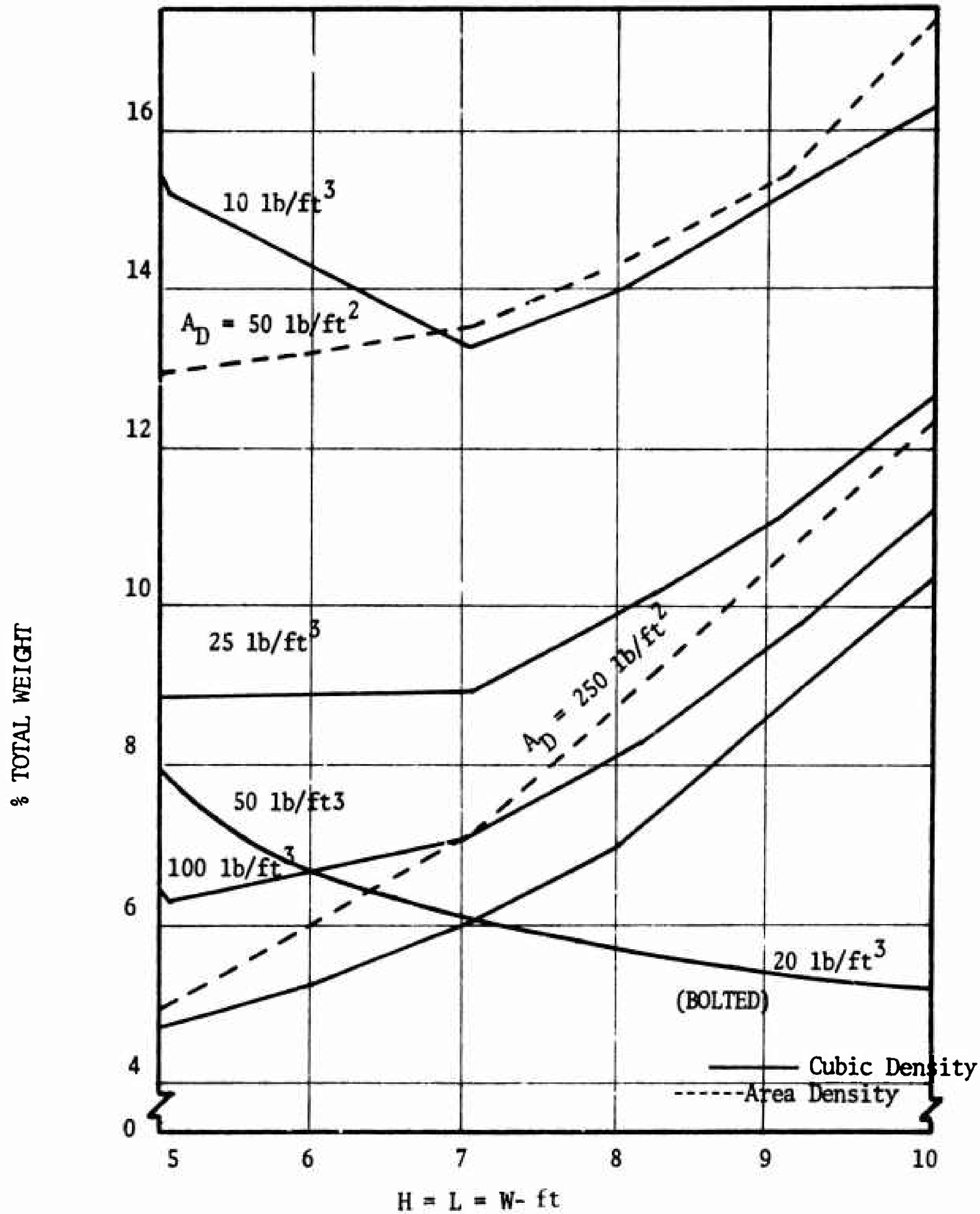

Figure B-2. Cubic Gondola Weight Ratio (Welded).

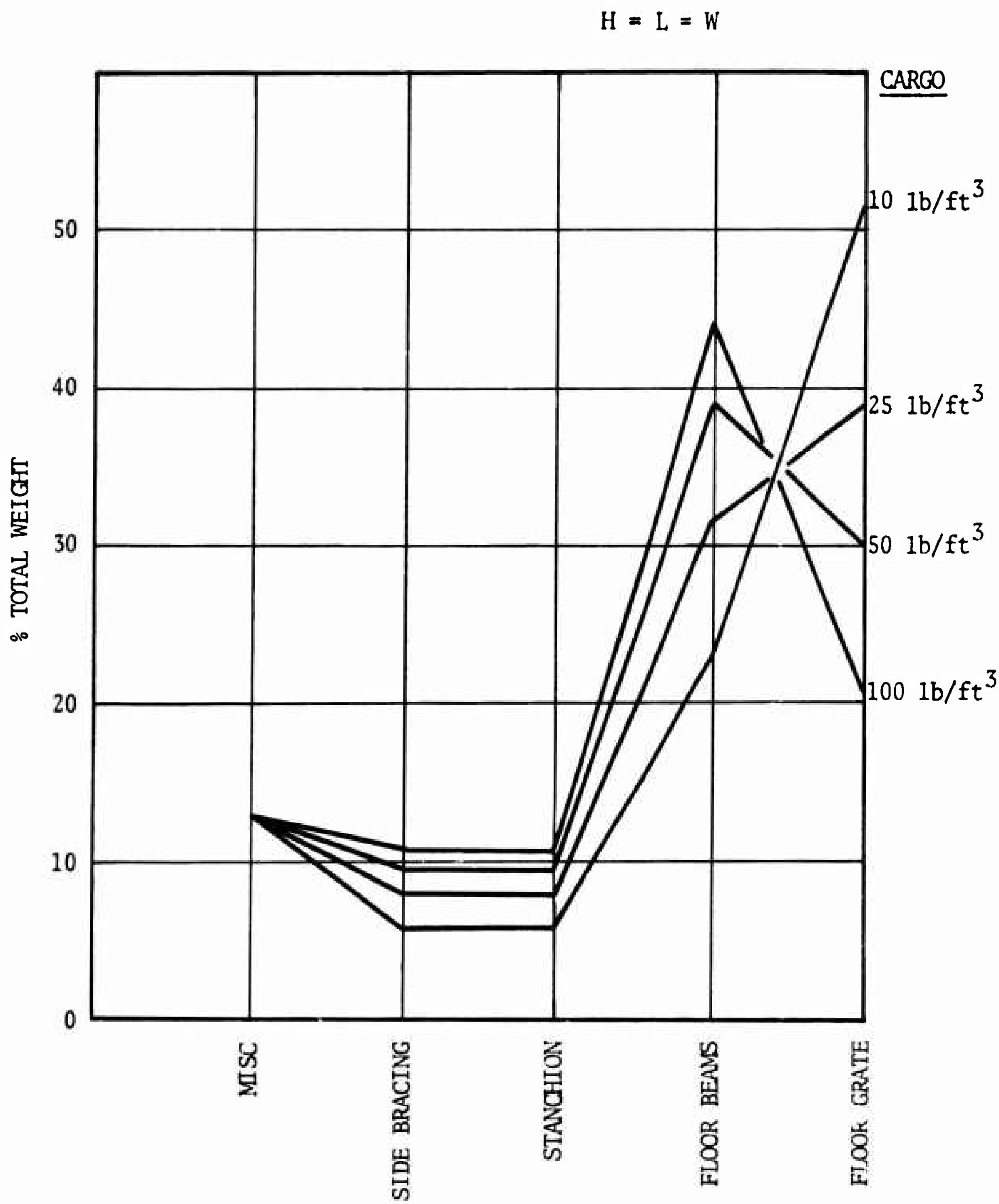

Figure B-3. Gondola Concept Weight Variance.

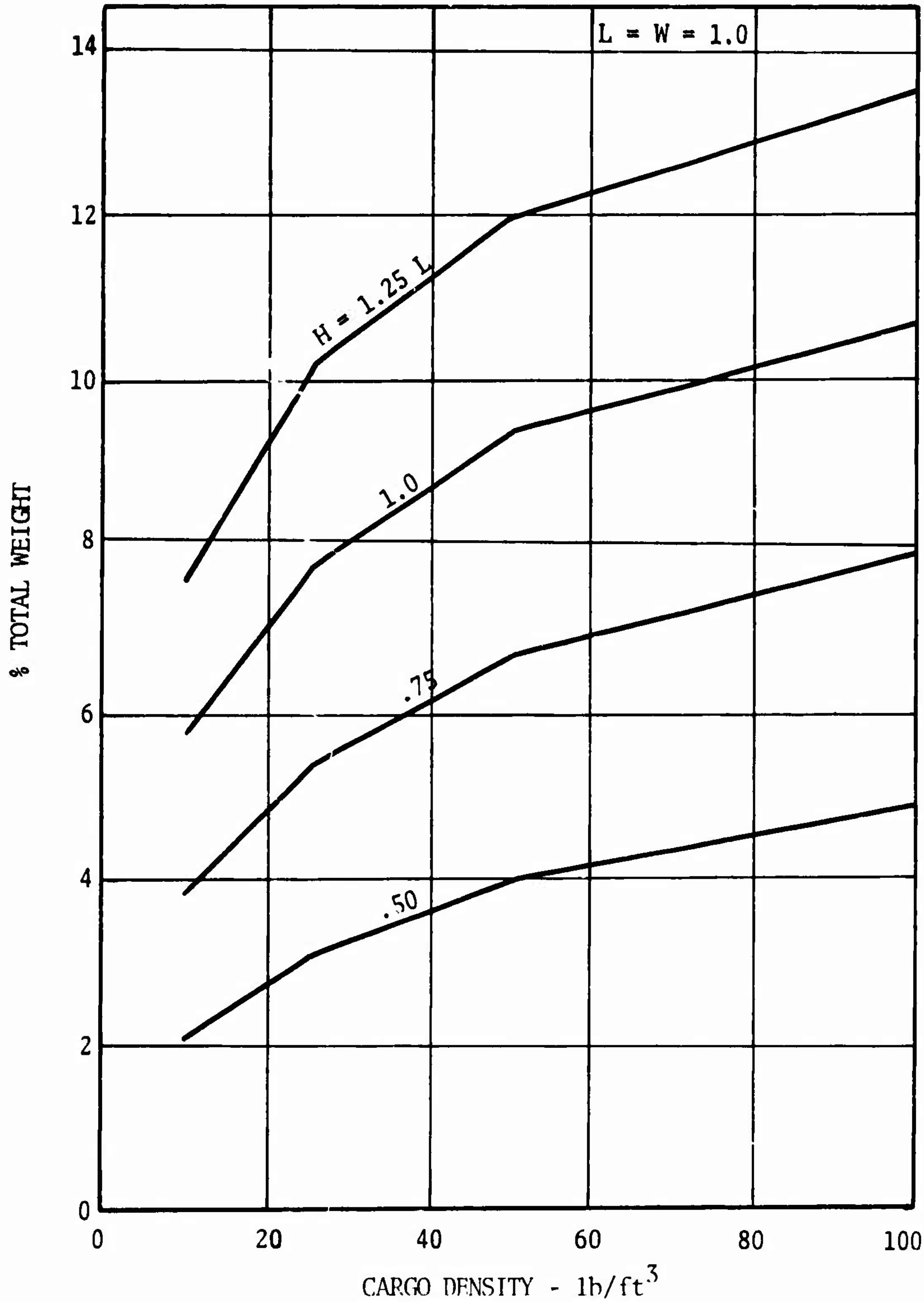

Figure B-4. Stanchion Weight Variation.

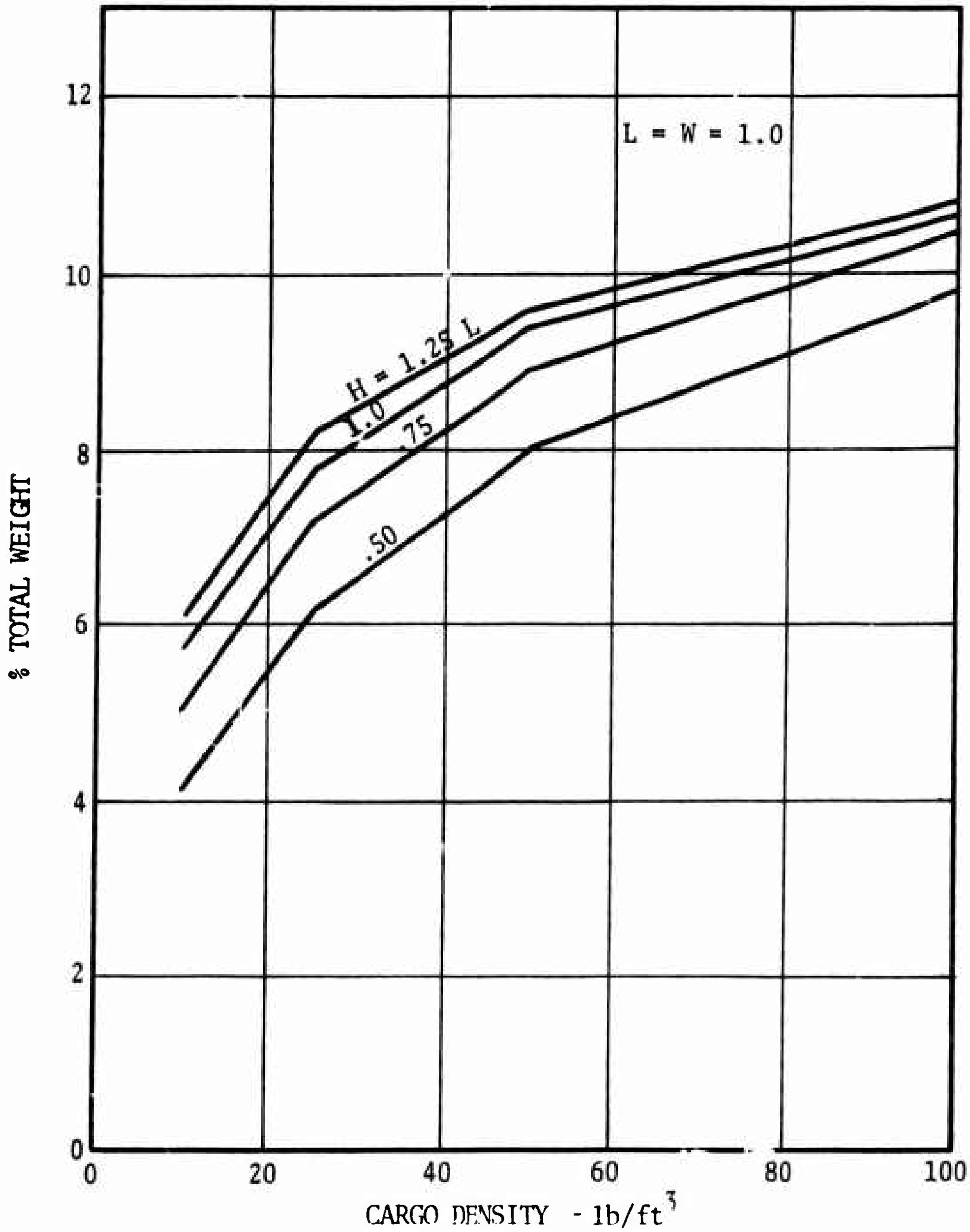

Figure B-5. Side Bracing Weight Variation.

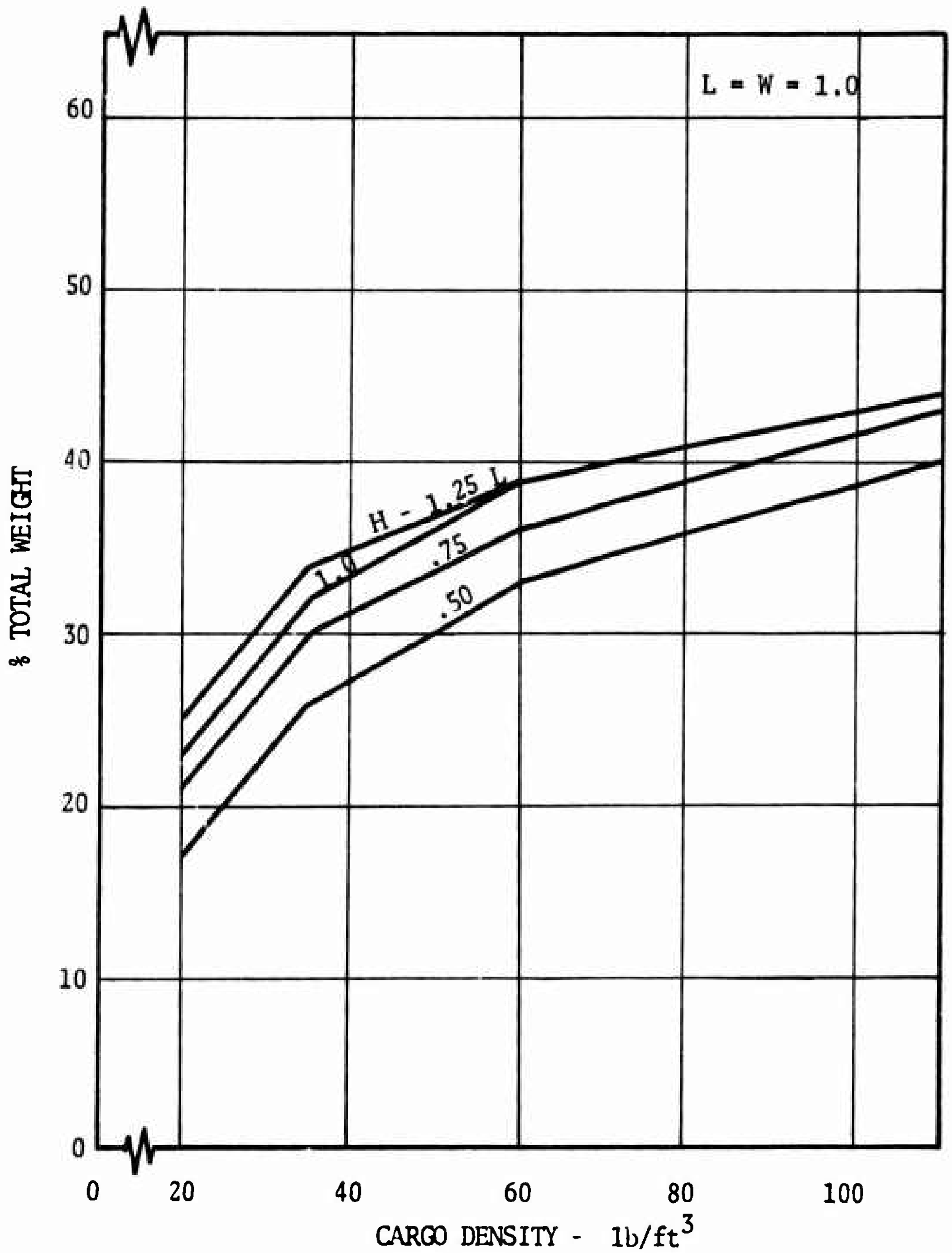

Figure B-6. Floor Beam Weight Variation.

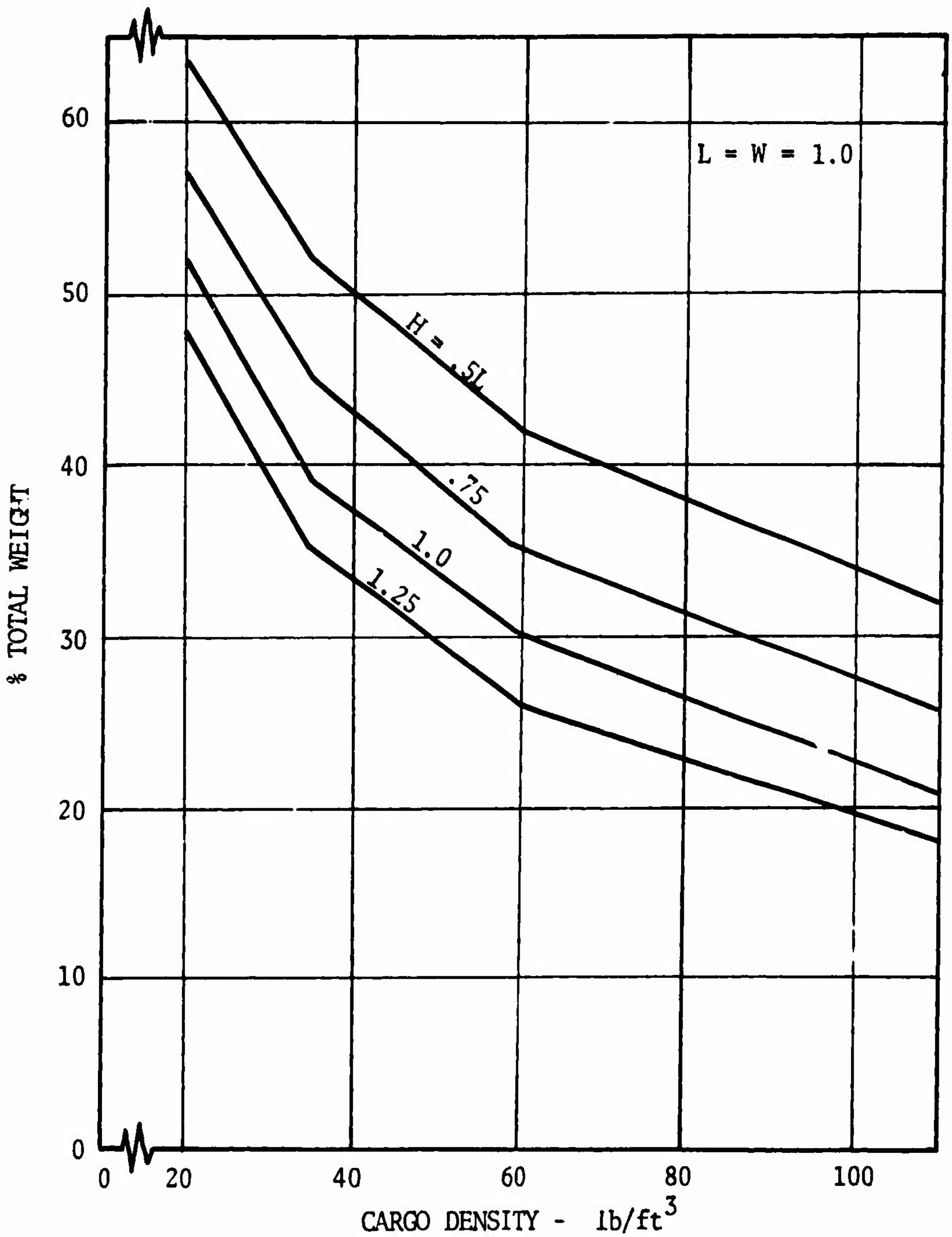

Figure B-7 Floor Grate Weight Variation.

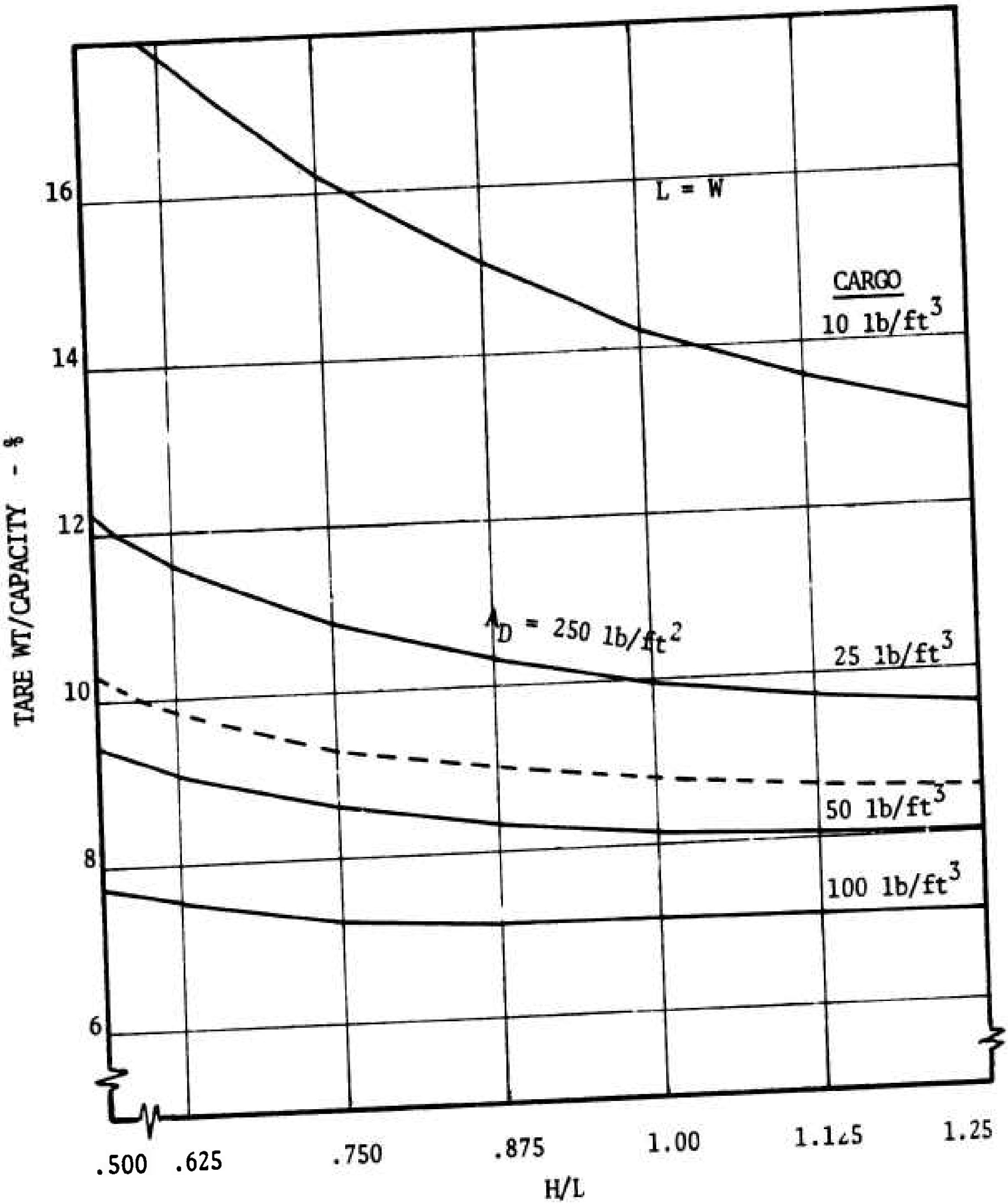

Figure B-8. Gondola Height-to-Length Ratio vs. Weight.

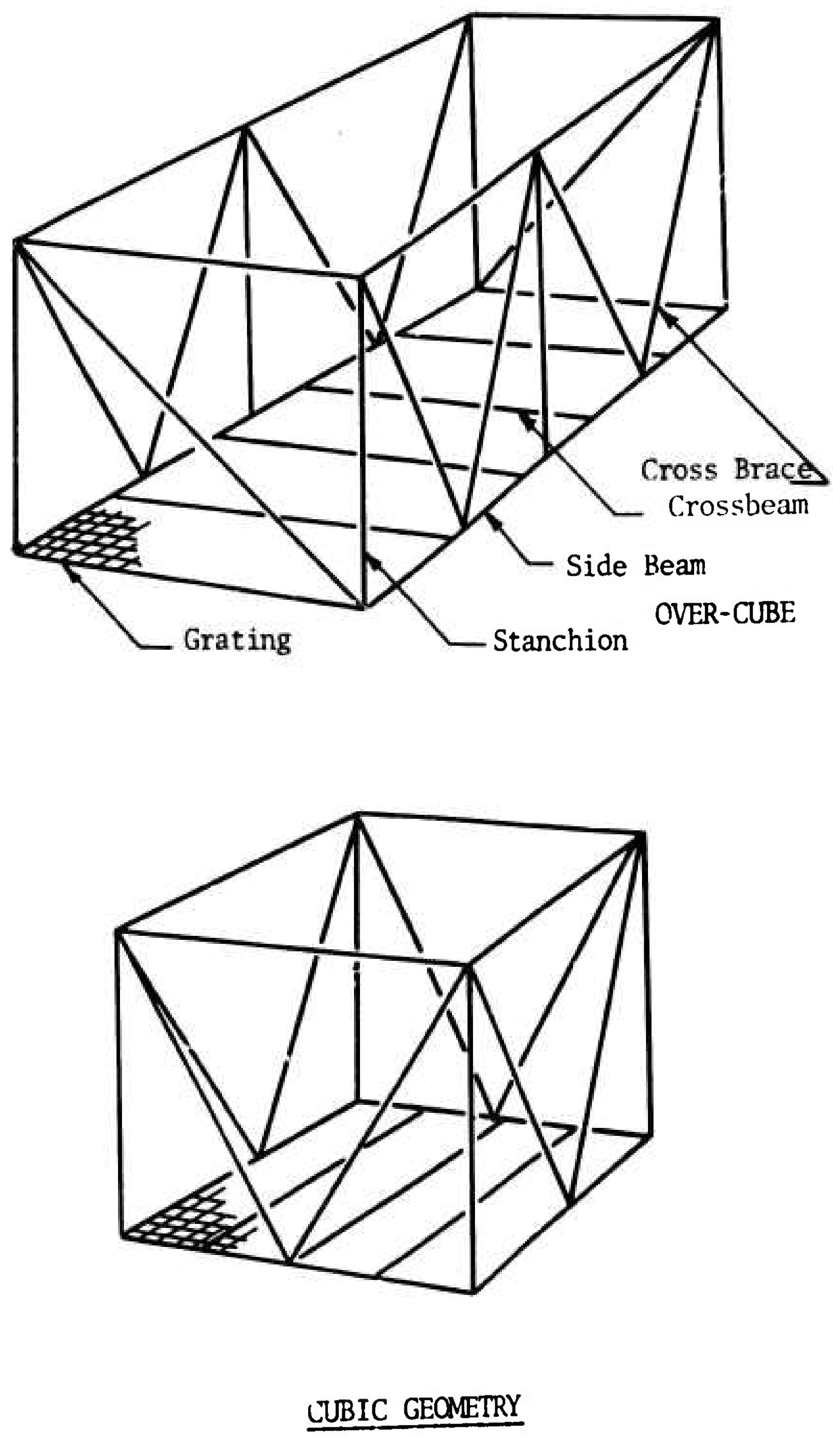

Figure B-9. Typical Cube and Over-Cube Gondola Configurations.

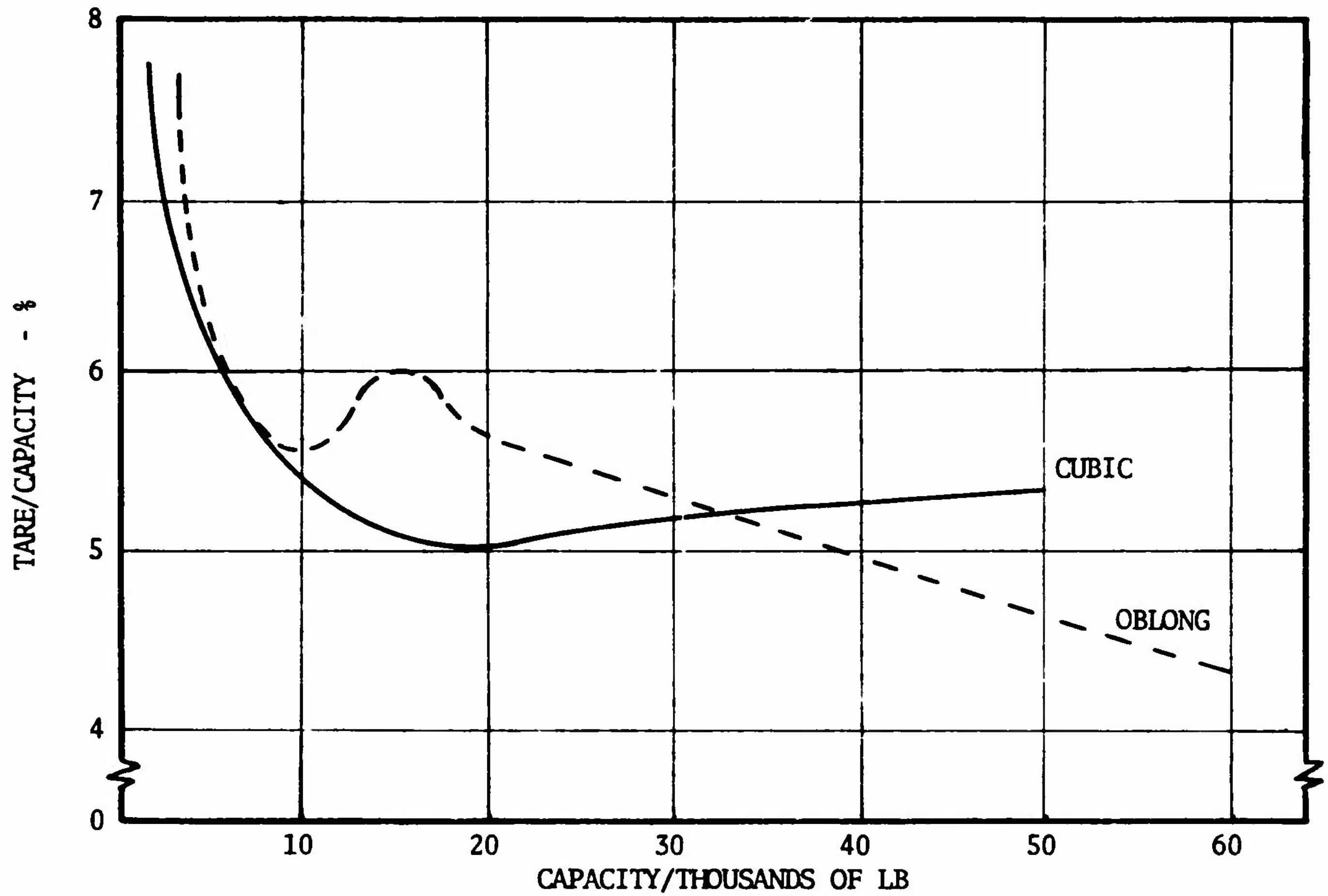

Figure B-10. Comparative Tare Weight of Cube vs. Over-Cube Gondolas.

COMPARATIVE ANALYSIS - CUBIC VS. OBLONG GONDOLA

I. CRITERIA

General Pallet Design Criteria

20 lb/ft^3 density cargo

Net loads of 20,000 lb and 50,000 lb

Useable volume = $(L-1)(W-1)(H-1/2)\ ft^3$

II. 20,000-lb CARGO

$V_{REQ'D} = 20{,}000/20 = 1{,}000\ ft^3$

A. CUBIC

Assume 11-ft sides

$V = (11-1)(11-1)(11-1/2) = 1{,}050\ ft^3$

$LD = 20{,}000\ (3)/\{(11-1)(11-1)\} = 600\ lb/ft^2$

1. GRATING

GIA 1 in. provides 691 lb/ft^2 capacity at 2-ft support spacing.

Support at 11/5 = 2-ft 2.4-in. spacing

$WT = 1.93\ (11)(11) = 233.5\ lb$

2. FLOOR CROSSBEAMS

$LD = 600\ (2.2)(11) = 14{,}520\ lb$

$M = 14{,}520(11)(12)/8 = 239{,}580$ in.-lb

$S_R = 239{,}580(1.5)/42{,}000 = 8.556\ in.^3$

use 8-in.-x-4.25-lb-channels

$WT = 4.25\ (6)\ 11 = 280.5\ lb$

3. FLOOR SIDE BEAMS

LD for 5.5 ft span = 15,000 lb

M = 15,000(5.5) 12/8 = 123,750 in.-lb

S_R = 123,750(1.15)/15,000 = 9.488 $in.^3$

use 7 [5.27

WT = 5.27(2) 11 = 115.9 lb

4. STANCHION

LD = (11/5) .144 (20,000) = 6336 lb C.

LD = 3(.250) 60,000/8 = 5,625 lb T.

$$r^2A = \frac{(11)^2\ 6336\ (114)}{\pi^2\ 10^7} = 1.119\ in.^4$$

use 3 D - 1/8 t

WT = 1.328 (4) 11 = 58.4 lb

5. CROSS BRACE

LD = (12.083/11.0)(5/8) .250 (60,000) = 10,298 lb T.

LD = (12,083/5) .144 (20,000) = 6,960 lb C.

A_R = 10,298 (1.5)/42,000 = .368 $in.^2$

$$r^2A = \frac{(12.083)^2\ 6,960\ (144)}{\pi^2\ 10^7} = 1.483\ in.^4$$

use 3-1/4 D - 1/8 t

WT = 1.443 (8) 12.083 = 139.5 lb

6. UPPER BRACE

LD = (5/11)(5/8)(.250) 60,000 = 4,251 lb C.

LD = .144 (20,000) = 2,880 lb C.

$$r^2A = \frac{(12.083)^2\ 6,960\ (144)}{\pi^2\ 10^7} = 1.483\ in.^4$$

6. UPPER BRACE (continued)

use 2-3/4 D - 1/8 t

WT = 1.212 (11) 4 = 53.3 lb

7. SUMMARY 11 FOOT CUBIC (20,000 LB CAP)

Grating - Gary GIA - 1 in.	233.5 lb
Floor Cross Beam	280.5 lb
Floor Side Beam	115.9 lb
Stanchion	58.4 lb
Cross Brace	139.5 lb
Upper Brace	53.3 lb
NET	881.0 lb
MISCELLANEOUS	135.0 lb
TOTAL	1,016.0 (5.08%)

B. OBLONG

Assume 8-x-20-x-8-ft

$V = (20-1)(8-1/2)(8-1) = 997.5 \text{ ft}^3$

This is the standard 20-ft gondola previously analyzed.

WT = 1124.5 lb

C. CONCLUSION

Cubic WT = 1,016.0 lb (5.08%)

Oblong WT = 1,124.5 lb (5.62%)

WT penalty is 108.5 lb or 11% of tare of cubic.

III. 50,000 LB. CARGO

$V_{REQ'D} = 50,000/20 = 2,500 \text{ ft}^3$

A. CUBIC

Assume 14.5-ft sides

$r = (14.5-1)\ (14.5-1)\ (14.5-1/2) = 2{,}551.5\ \text{ft}^3$

$LD = 50{,}000\ (3)/[(14.5-1)(14.5-1)] = 823.0\ \ \text{lb/ft}^2$

1. GRATING

GIA 1-1/4" provides 1,007 lb /ft^2 capacity at (14.5/7) support spacing.

$WT = 2.32\ (14.5)(14.5) = 487.8\ \text{lb}$

2. FLOOR CROSS BEAMS

$LD = (14.5/7)\ 14.5\ (823) = 24{,}716\ \text{lb}$

$M = 24{,}716\ (14.5)\ 12/8 = 537{,}647\ \text{in.-lb}$

$S_R = 537{,}647(1.5)/42{,}000 = 19.2\ \text{in.}^3$

use 9 I 7.51

$WT = 7.51\ (8)\ (14.5) = 871.2\ \text{lb}$

3. FLOOR SIDE BEAMS

$LD = 37{,}500\ \text{lb}$

$M = 37{,}500\ (14.5)(1/2)\ 12/8 = 407{,}813\ \text{in.-lb}$

$S = 407{,}813\ (1.15)/15{,}000 = 31.266\ \text{in.}^3$

use 12 I 10.99

$WT = 10.99\ (2)\ 14.5 = 318.7\ \text{lb}$

4. STANCHION

$LD = 2\ (.144)\ 50{,}000 = 14{,}400\ \text{lb}\ \ C.$

$LD = 3\ (.250)\ 150{,}000/8 = 14{,}063\ \text{lb}\ \ T.$

4. <u>STANCHION</u> (continued)

$$r^2A = \frac{(14.5)^2 \; 14,400 \; (144)}{\pi^2 \; 10^7} = 4.417 \text{ in.}^4$$

use 4-3/4 D - 1/8 t

WT = 2.136 (4) 14.5 = 123.9 lb

5. <u>CROSS BRACE</u>

LD = (16.211/14.5)(5/8) .250 (150,000) = 26,204 lb T.*

LD = (16.211/7.25) .144 (5[illegible]00) = 16,099 lb C.*

A_R = 26,204 (1.5)/42,000 = .9[illegible]6 in.^{2}

$$r^2A = \frac{(16.211)^2 \; 16,099 \; (144)}{\pi^2 \; 10^7} = 6.173 \text{ in.}^4$$

use 4-3/4 D - 3/16 t

WT = 3.161 (8) 16.211 - 409.9 lb

6. <u>UPPER BRACE</u>

LD = (1/2)(5/8) .250 (150,000) = 11,719 lb C.

$$r^2A = \frac{(14.5)^2 \; 11,719 \; (144)}{\pi^2 \; 10^7} = 3.595$$

use 4-1/2 D - 1/8 t

WT = 2.020 (4) 14.5 = 117.2 lb

7. <u>SUMMARY</u> <u>14.5 FOOT CUBIC</u> (50,000 LB CAP.)

Grating - Gary GIA - 1-1/4 in.	487.8 lb
Floor Crossbeam	871.2 lb
Floor Side Beam	318.7 lb
Stanchion	123.9 lb
Cross Brace	409.9 lb
Upper Brace	117.2 lb

*Denotes Tension (T) Compression (C)

7. SUMMARY 14.5-Ft CUBIC (50,000 LB CAP.) (continued)

NET	2,328.7 lb
MISCELLANEOUS	350.0 lb
TOTAL	2,678.7 (5.36%)

B. OBLONG

Assume 8-x-40-x-9-1/2 ft

$V = (40-1)(8-1)(9\text{-}1/2 - 1/2) = 2{,}457\ ft^3$

1. GRATING

LD = 50,000 (3)/320 = 468.8 lb $/ft^2$

GIA 1 in. provides 499.2 lb $/ft^2$ capacity at (40/17) support spacing.

WT = 1.93 (408) = 617.6 lb

2. FLOOR CROSS BEAMS

LD = 468.8 (8) 40/17 - 8,824 lb

M = 8,824 (96)/8 = 105,894 in.-lb

$S_R = 105{,}894\ (1.5)/42{,}000 = 3.782\ in.^3$

use 6 [2.83

WT = 2,83 (8) 18 = 407.5 lb

3. FLOOR SIDE BEAMS

LD = 150,000/16 = 9,375 lb

M = 9,375 (5) (12)/8 = 70,312 in.-lb

$S_R = 70{,}312\ (1.15)/15{,}000 = 5.390\ in.^3$

use 5 I 4.23

WT = 4.23 (2) 40 - 338.4 lb

Remaining members are essentially the same as on the 40-foot coupled gondola previously analyzed.

4. SUMMARY 40-Ft OBLONG (50,000 LB CAP.)

Grating GIA 1 in.	617.6 lb
Floor Crossbeams	407.5 lb
Floor Side Beams	338.4 lb
Stanchion - Corners	91.3 lb
Stanchion - Center	16.0 lb
Upper Brace	19.4 lb
End Brace	78.8 lb
Side Brace	114.0 lb
Top Longitudinal	349.8 lb
NET	2,032.8 lb
MISCELLANEOUS	300.0 lb
TOTAL	2,332.8 (4.67%)

C. CONCLUSION

Cubic WT = 2,678.7 lb (5.36%)

Oblong WT = 2,332.8 lb (4.67%)

WT Saving is 345.9 lb or 13% of tare of cubic.

It is seen that the oblong gondola becomes more efficient as the cubic gondola crossbeams become excessively long and their weight increases to a disproportional amount of the total gondola weight.

TABLE B-1
CUBIC DESIGN SUMMARY

SIZE (FT)	VOL. (FT^3)	CAPACITY (LB)	GRATING (LB)	CROSS BM (LB)	SIDE BM (LB)	STANCHION (LB)	CROSS BRACE (LB)	UPPER BM (LB)	ΣWT (LB)	MISC (LB)	TOTAL WT (LB)	% TARE
11	1050	20,000	233.5	280.5	115.9	58.4	142.0	53.3	883.6	135	1018.6	5.09
10	770	15,400	193	212.4	86	48.5	118.8	43.9	702.6	100	802.6	5.21
9	544	10,880	156.3	152.1	61.7	22.4	97.6	20.3	510.4	75	585.4	5.38
8	368	7,355	123.5	113.2	42.2	14.2	40.3	14.3	347.7	50	397.7	5.41
7	234	4,680	94.6	65.0	60.2	9.3	22.3	9.3	260.7	40	300.8	6.43
6	138	2,750	69.5	41.5	31.7	3.4	13.2	3.4	162.7	25	187.7	6.83
5	72	1,440	48.3	21.3	19.6	2.8	4.0	2.8	98.8	15	113.8	7.90
4	32	630	30.9	17.0	15.7	2.5	3.2	2.3	71.4	12	83.4	13.24
3	10	200	17.4	8.5	11.8	1.7	2.4	1.7	43.5	6	49.5	24.75

APPENDIX C
SURVEY OF TECHNOLOGY

A survey of technology was conducted throughout Tasks A and B of the study program for Phase I. This survey included a review of pertinent reports and technical manuals, and letter interviews with commercial helicopter operators and suppliers of pallets and external cargo hardware. Performance parameters of stability and dynamic load factors together with the logistic and technical requirements were obtained from the reports and technical manuals and bulletins. The survey of commercial helicopter operators and pallet gondola suppliers revealed that few helicopters are in use with the capability of the CH-47, CH-54, and HLH. Virtually no pallet or gondola is specifically designed for helicopter external transport.

Pallets/Gondola Equipment

Availability of pallets/gondolas used for external cargo application is extremely limited. As a result, little pertinent design or performance information is available. However, a pallet/gondola system was recently designed, fabricated, and tested to transport the AN/TPN (PAR, ASR, and OPS/B). This system incorporated several design features which are directly applicable to the performance criteria established.

Pallet suppliers' data is shown in Table C-1. Similarly, the response of the helicopter operators is shown in Table C-2.

Evaluation of the data obtained during our technology survey reveals that little or no attention has been given to cargo pallets/gondolas for external transport by helicopter. A contributing factor, of course, is the limited usage of large cargo helicopters in commercial applications. Similarly, the more recent application of the CH-47 and CH-54 in transporting external loads was hampered by the lack of suitable break bulk cargo carrying equipment. Therefore, the impetus to develop such equipment was restricted. The response to the letters of inquiry to pallet manufacturers was minimal. Those that did respond had virtually nothing to offer in satisfying the performance requirements. However, some design features and materials utilized in present pallet technology may be applicable to the anticipated design concepts. In general, the pallets were payload limited, cube limited, and without provisions for helicopter lifting as external loads. It was determined that one gondola used in offshore resupply of Canadian villages was transported by a CH-54 helicopter. This gondola, rectangular in shape, was compatible with ship container cells and could be attached for external cargo transport by helicopter. However, the tare weight was approximately 20% of payload. This pallet/gondola together with the AN/TPN System had design features which could satisfy some of the performance criteria. A summary of the pallet/gondola survey is shown in Table C-1.

Physical Characteristics

Evaluation of the physical characteristics of pallets/gondolas was limited by the response of the manufacturers and the fact that pallets/gondolas designed specifically for external helicopter transport are virtually non-existent. Various types of construction were used, ranging from molded plastic to welded/riveted aluminum and steel. One and possibly two of the pallet/gondolas reviewed considered the high vertical load factors and/or the dynamic loading that would be experienced in continued usage. Two of the designs provided lift points above the load center of gravity. These load points had secondary supports and provided a compressive load side member which would be required on long pallets. Most of the pallets were strictly load bearing with little provision for multimodal transportability. The material incorporated in the various designs utilized aluminum more than any other. Aluminum offers good strength-to-weight ratios and cost-strength to weight is likewise good. However, some aircraft quality alloy steels may be more desirable in reducing tare weight. Methods of joining the main structural members of all the pallets were invariably welding, bolting, or riveting the connections. While welding offers desirable repairability, the heat-affected zone of high-strength alloys would be compromised. Therefore, it appears that the use of standard mechanical fasteners may be preferred. Experience in repairing pallets and that of the maritime industry on containers, it is suggested that the use of sheet stock be avoided where possible. Due to rough handling environments which are inherent in cargo transport, it is suggested that rugged structural shapes be utilized to the maximum extent. Additionally, the joining of sheet stock by adhesive bonding either to sandwich cores or to structural members is susceptible to corrosive degradation resulting in delaminations which are difficult to repair even at depot levels. While bonded structures are not excluded, their application would be restricted due to the impediments imposed by their use with sheet stock.

Logistical/Technical Requirements

The pallet/gondola survey indicated that all the pallets satisfied one or more of the logistical/technical mission requirements, but no single one satisfied all. Mission suitability of the existing designs was only coincidental to a particular feature. Consideration for cargo restraint attachment to the helicopter and rigging was almost universally ignored. Invariably, the designs were directed toward transporting definite loads peculiar to one application. However, the load bearing pallets did permit ease of loading/unloading, and cargo could be secured by straps. Equipment interface with regard to interchangeability was incorporated on the AN/TPN pallet set. However, this was restricted to removable secondary structural members. This same pallet utilized standard AN, NAS, and MS hardware for mechanical fasteners, etc. Sufficient design data was not obtained from other manufacturers to assess interchangeability and standard hardware.

Some of the pallets incorporated recessed tie-down restraints, while others had restraints only at the edges. Most of the pallets surveyed had flush floor surfaces, which is undesirable from two points: (1) the empty return is hampered by large flat plate drag which induces oscillation, and (2) a nonporous floor surface restricts lashing and tie-down. The ERC pallet is a simple X-braced rectangular frame which is desirable for porosity; however, some rigid grating would be required to prevent small object fallout. An additional desirable feature of this pallet is its payload-to-tare weight ratio, which appears to be quite low. Since most of the pallets were designed for load bearing and forklift transportability, little design consideration was given to the higher section modulus induced by sling attachment at the pallet corners above the CG. This requirement, together with the higher load factors, suggests that elevated side and end members be used to provide the desired section modulus. This design feature was incorporated on two of the pallets surveyed.

Personnel effectiveness on most of the pallets was acceptable except the pallets that restricted loading/unloading by nonremovable side or end supports. Additionally, some of the designs had no forklift tineways, which are necessary from our study. Lack of sufficient tie-down restraints was similarly observed. In instances where hardware was removable, it was not of a captivated nature to minimize losses. These deficiencies must be minimized to the maximum extent to meet the operational suitability and maintainability. Maintainability/repairability must be incorporated in the ruggedness of design to permit a level of misuse that the equipment will experience as demonstrated by container damage history. The pallet/gondola and container designs observed were invariably lacking in this design characteristic. As a result, the pallet/gondola maintainability/repairability will be dictated by ruggedness of the design. Ruggedness of the design could satisfy handling environment and load spectrum (ultimate load factors and dynamic loads), but must minimize tare weight. Therefore, the maintainability/repairability may be satisfied by the judicious placement of rugged members to take maximum advantage of their strength and section properties.

Application of Commercial Pallets/Gondolas

Application of commerically available pallets and gondolas to satisfy the performance requirements of the study was not determined. However, the adaptability of some features for utilizing load-bearing pallets appears feasible. Of particular interest was the utilization of the standard 48-x-40-in. load bearing pallet in a gondola frame. Although this concept induces a 200- to 500-lb weight penalty, it utilizes the pallets as both a prepackaging device and a continuous floor for bulk cargo. Additionally, the relatively inexpensive pallet permits forklift unloading or manual unloading. It is further anticipated that the 463L pallet could be utilized as a slave unit when transporting the gondola by fixed wing as internal cargo. A listing of various types of pallets/gondolas is presented in Table C-1.

TABLE C-1

PALLET GONDOLA SUPPLIERS

(pg 1 of 2)

PALLET/GONDOLA	SIZE (in.)	WEIGHT (lb)	CAPACITY (lb)	FORKLIFT	FABRICATION	ACCEPTABILITY	ADAPTABILITY
A	40 x 48 x 6	48	25,000 Bearing	yes	Molded Polyethelene	Size limited. No lift attachment points. Good corrosion Risistance & Impact	Possible application as a pallet cell.
B	None given	-	-	-	Rectangular Grided metal base Grided wire sides Structural shapes Welded & mechanically fastened.	Size limited No lift attachment Generally not acceptable.	Remote
C	80 x 102 x 6-3/4	207.5	10,000 Bearing	no	Rectangular X-braced Load pallet--structural Shapes, riveted Corner lift rings Apparently all aluminum	Size limited. Lift points below C.G. Surface not continuous	Possible application as a pallet base porours floor desirable.
D	77 x 96 x 6	280	unknown	yes	Rectangular X-braced Aluminum structure with flush aluminum skin bearing surface, with tie-down rings, riveted connections	Size limited No lift points Nonporous floor	Remote
E	104.5 x 360 x 6.75	1700	22,500 Bearing	no	Rigid frame-bolted with Bonded honeycomb cells Flush top and bottom surfaces. Aluminum structural shapes and plate	Adequate size Couples to 600". No lift points, tie-down rings 20 in. on centers. Accepts side rail lock pins for fixed-wing internal cargo	Cannot accept vertical lift at capacity load Cannot accept elevated lift points; high tare weight
E	85.5 x 144 x 7	1062	12,500* Lifting	yes	Aluminum structural shapes and plate. Riveted, welded and bolted joints.	Elevated lift points Low payload efficiency Accepts mobilizer dolly Can be transported by rail, truck, fixed wing, and helicopter Flush load surface	Has many features desirable for application.
E	71.1 x 85.5 x 7	715	12,500* Lifting	yes	same as E	Same as E	Same as E
E	71.1 x 85.5 x 7	525	12,500* Lifting	yes	same as E	Same as E	Same as E

TABLE C-1
PALLET GONDOLA SUPPLIERS

(pg 2 of 2)

PALLET/GONDOLA	SIZE (in.)	WEIGHT (lb)	CAPACITY (lb)	FORKLIFT	FABRICATION	ACCEPTABILITY	ADAPTABILITY
F		4400	22,400	no	Welded steel frame, wood plank floor	Acceptable size. Low payload efficiency. Tie-downs at edge only. Extendable corner post.	Has some desirable features. Not designed for helicopter load factors. Has multimodal capability
G	86 x 120 x 5.5	600	20,000	yes	Extruded aluminum. Frame riveted to castings. Sandwich bonded balsa. wood and aluminum skins.	Size adequate when coupled. Flush floor. Insufficient tie-downs. Good Payload efficiency	Unstable for empty flight. Load points below C.G.--unstable bonded structure questionable. Alum sheet susceptible to impact damage and compression
H	88 x 240 x 5.5	1100	20,000	yes	-same-	-same-	-same-

*Lifting eye limited

Of the pallets/gondolas listed, two types warrant evaluation of particular features: gondolas having elevated load points and gondolas having upper support structure. A synoptic evaluation of their features is presented on the following pages.

The Type E pallet had the following features:

ADVANTAGES

Elevated Load Attachment Points
Removable End Supports With Interchangeability
Forklift Tineways
Towing/Skid Eyes
Shock-Absorbing Skid
Coupled Sections
Captivated and Standard Hardware

DISADVANTAGES

High Tare Weight
Nonporous Floor Area
Limited Cargo Restraint
Nonmovable Siderails
Light Weight Edge Members
Cube Limited
Fixed Lift Points

The Type F gondola was evaluated as follows:

ADVANTAGES

Cubic Capacity
Removable End and Side Support
Extendable Corner Post
Multimodal Transportability
Rugged Construction
ANSI/ISO Corner Fittings

DISADVANTAGES

High Tare Weight
Edge Tie-Downs Only
No Forklift Ways
Nonporous Floor
Weight Limited

Sufficient design detail was not available on the Type F gondola to conduct a thorough evaluation. The Type E pallet, which carried delicate radar equipment, had unique requirements which imposed weight penalties for shock attenuation beyond that required for a general-purpose pallet/gondola. As reflected from our inquiries, no known hardware embodies the design optimization required for the intensive use of pallets/gondolas as external cargo.

Containers

Containers and their performance present certain criteria that are applicable to the pallet/gondola concept. Although the container incorporates many design features not required for pallets/gondolas, several characteristics are analogous. Such attributes as ruggedness, corrosion resistance, and arctic weather operation are applicable. Vulnerability to damage, especially to the floor/base members, is closely related to that of a gondola and end and side supports to the walls of the container. One of the principal causes of failure was handling damage occurring in the base structure. The member most prone to this damage is the lateral edge member. This fact will, of course, be significant in the pallet/gondola design which, in at least some concepts, will utilize this member as a primary structural load path. Damage to these members is experienced from forklift tine impact and in some instances failure through stress concentrations caused by fastener locations.

Although the container design constraints do not address the performance requirements of helicopter transport specifically, such interfaces in terminal handling and intermodal transportability are similar.

Commercial Helicopter Operator Survey

A survey of commercial helicopter operators was conducted to determine their critique in transporting external cargo. It is unfortunate that few commercial operators have helicopters with the external payload capability of the CH-47, CH-54, or HLH. However, the data supplied by the operators generally corroborates operational characteristics experienced by the military. Although the data is limited, the overall response reflects trends which are consistent with the study parameters. A corroboration is presented by the area density (A_D) of the cargo and the flight speed reported. Where flight speeds were reported to be above 60 knots, the load area density was medium. Similarly, where low area density loads were flown, flight speeds of 40 knots were reported. The nominal trip length appears to be 25 miles or less with occasional trips to 80 miles and in some instances short shuttle lengths under a mile.

Rigging and hookup are generally accomplished in less than 30 minutes and 1 minute respectively. These times appear reasonable for the relatively small loads transported. The single operator flying the S-64 helicopter reported a low rigging time compared to the smaller loads carried by other operators. Several operators expressed their desire of a gondola, although one operator thought they would be dangerous. While few specific conclusions can be drawn from the limited data, trends appear to support other sources with respect to cargo density, area density, and flight speeds. Data from inquiries made to commercial operators is presented in the following table.

TABLE C-2
COMMERCIAL HELICOPTER OPERATORS

(pg 1 of 2)

COMMERCIAL USER COMPANY	HELICOPTER MODEL	CARGO TYPE	LOAD (lb)	CUBE DENSITY LB/ft^3	AREA DENSITY LB/ft^2	TRIP LENGTH (MILES)	GROUND SPEED (MPH)	REMARKS
A	S64-E	Break-bulk; fuel & oil	16,000 to 18,000	12.5 to 14.0	100.0 to 112.5	10-15	90-100	Light, bulky loads reduce flying speeds. Do not use nets--cargo crush would use 8' x 8' x 20' gondola
	S61-N	Various equip-ment & break-bulk	1,200 to 3,500	6.25 to 18.23	25 to 72.9	1/2	40	Used nets only once Would use pallets/gondolas if carrying several small items.
B	S61 S58T B-204 B-205	Vari-able	4,000 4,000 3,500 to 1,000	3.9 250.0 62.5 15.625	31.25 62.5	25 25 10 to 50	40 80 60 to 90	Nets are used with wood pallets; some loads are flown below 40 knots and some 100 knots. They usually fly below 80 knots. They would like an 8'x 8'x 20' pallet if they had a MS64.
C	B-47 B-206 B-205	Oil field tools Equip-ment and supplies	600 800 3,700			1 - 15 1 - 15 1 - 15 1 - 15	unk unk unk unk	Load oscillations restrict flying speed. Nets used. They feel pallets and gondolas are "dangerous".
D	S61N	Bulk Fruit & Veg. drums 44 gal, ships cargo	3,300	15.27	91.7	15	100	They would like small pallets/gondolas capable of internal storage on return flight.
E	S58-T B-212 B-205 B-206 B-47	logs, barrels, etc.	5,000 6,000 6,000 6,000 6,000	NO RESPONSE				
F	S-62	Oil field equipment, pipe, tools etc.	12,000 to 1,000			3-30	65 knots	Could use light weight and tough pallet/gondola.
G	S-58	Equipment	5,000	INCOMPLETE DATA	INCOMPLETE DATA	5-50	20-100 knots	Small pallet would be useful. Flying speeds are occasionally reduced due to load instability.
H	S-55	Various Equipment	2,500			2	60 knots	Would like pallet/gondola.

TABLE C-2
COMMERCIAL HELICOPTER OPERATORS

(pg 2 of 2)

COMMERCIAL USER COMPANY	HELICOPTER MODEL	CARGO TYPE	LOAD (lb)	CUBE DENSITY LB/ft^2	AREA DENSITY LB/ft^2	TRIP LENGTH (MILES)	GROUND SPEED (MPH)	REMARKS
I	S-58 S-55	Various Equipment	3,000 to 1,500			.5	40 knots	Would use one if available.
J	S-58T B-205	Oil field equipment	3,800			1/4-80	25-80	Load oscillations frequently reduce flying speeds.

LIST OF SYMBOLS

Symbol	Definition	UNITS
A	Area	ft^2
A_C	Area of Cargo	ft^2
A_d	Area of Blade Disk	ft^2
A_D	Area Density	lb/ft^2
$A_{D/C}$	Area of Cargo Covered by Rotor Disk	ft^2
$A_{D/H}$	Area of Helicopter Covered by Rotor Disk	ft^2
A_H	Area of Helicopter	ft^2
$A_{H/C}$	Area of Cargo Covered by Helicopter	ft^2
A_{MAX}	Maximum Frontal Area	ft^2
C_D	Coefficient of Drag (dimensionless)	
CG	Center of Gravity (dimensionless)	
E	Modulus of Elasticity in Tension, Young's Modulus	psi
E_C	Modulus of Elasticity in Compression	psi
F	Force	lb
F_{bru}	Ultimate Bearing Stress	psi
F_{bry}	Bearing Yield Stress	psi
F_{cy}	Compressive Yield Stress	psi
F_D	Drag Force	lb
F_{su}	Ultimate Stress in Pure Shear	psi
F_{tu}	Ultimate Tensile Stress	psi
F_{ty}	Tensile Yield Stress	psi
g	Acceleration of Gravity	ft/sec^2
H_{CG}	Height From Cargo to Ground	ft

List of Symbols (continued)

		UNITS
H_{DH}	Height From Rotor Disk to Helicopter Body	ft
H_{HC}	Height From Helicopter Body to Cargo	ft
IGE	In Ground Effect (dimensionless)	
L	Length	ft
LD	Load	lb
M	Moment	in.-lb
M_L	Moment Due to Lift	in.-lb
M_W	Moment Due to Weight	in.-lb
OGE	Out of Ground Effect (dimensionless)	
P_D	Downwash (Disk) Pressure	lb/ft^2
q	Dynamic Pressure	lb/ft^2
r	Radius of Gyration	in.
S	Section Modulus	$in.^3$
STON	Short Ton	2,000 lb
V	Volume	ft^3
V_{MAX}	Maximum Velocity	mph
ρ	Density of Air	$slugs/ft^3$